G. C. A. B.

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TO THE STUDENTS

OF

AVIATION

INTRODUCTION.

THE three numbers of THE AERONAUTICAL ANNUAL mentioned on the title-page being now out of print, the editor has selected several of the most important articles and reprinted them here.

This compilation has for its primary object the encouragement of those who are just beginning the study of aviation.

In the effort to reach a good understanding of the achievements of to-day the student may do well to learn of the work of the pathfinders.

MAY, 1910.

CONTENTS.

LIST OF PLATES.

LILIENTHAL.

Born, 1848; Died, 1896.

THE epoch-making work of Otto Lilienthal gave ocular demonstration of two facts which before his time had been generally disbelieved.

First: That it is possible for a man, in free flight, using extended surfaces of moderate dimensions, to derive support from the impact of the air upon those surfaces without the aid of the buoyant power of a gas lighter than air.

Second: That it is possible for a man, in free flight, to acquire a fair degree of control of an aeroplane apparatus.

[From Aero. Ann., 1896.]

PRACTICAL EXPERIMENTS FOR THE DEVELOPMENT OF HUMAN FLIGHT.

By Otto Lilienthal.

(Written expressly for the Annual.)

Whoever has followed with attention the technical treatises on flying will have become convinced that human flight cannot be brought about by one single invention, but is proceeding towards its perfection by a gradual development; for only those trials have met with success which correspond with such a development.

Formerly men sought to construct flying machines in a complete form, at once capable of solving the problem, but gradually the conviction came that our physical and technical knowledge and our practical experiences were by far insufficient to overcome a mechanical task of such magnitude without more preliminaries.

Those proceeding on this basis therefore applied themselves, not to the problem of flying as a whole, but rather divided it into its elements, and sought first to bring a clear understanding into said elements which should form the basis of final success. For example, take the laws of atmospheric resistance, upon which all flying depends, and regarding which, until very recent years, the greatest uncertainty has existed; these have now been defined to such an extent that the different phases of flight can be treated mathematically. Besides which, the physical processes of the natural flight of the creatures have become the subject of minute investigation, and have in most cases been satisfactorily explained. The nature of the wind also, and its influence on flying bodies, have been carefully

studied, thus enabling us to understand several peculiarities of the birds' flight hitherto unexplainable, so that one can apply the results thus obtained in perfecting human flight.

The theoretical apparatus needed for the technics of flying has been enriched so much by all these studies within the last few years that the elements of flying apparatus can now be calculated and constructed with sufficient accuracy. By means of this theoretical knowledge one is enabled to form and construct wing- and sailing-surfaces according as the intended effect renders it desirable.

But with all this, we are not yet capable of constructing and using complete flying machines which answer all requirements. Being desirous of furthering with all speed the solution of the problem of flight, men have repeatedly formed projects in these last few years which represent complete air-ships moved by dynamos; but the constructors are not aware of the difficulties which await us as soon as we approach the realizing of any ideas in flying.

All those, who have occupied themselves to any extent with actual flying experiments, have found that, even if they mastered theoretically the problem of flying, the practical solving of the same can only be brought about by a gradual and wearisome series of experiments based one upon the other.

Also the practical tasks of the technics of flying should be simplified and divided as much as possible instead of steering straight to the final goal.

As these principles have been seldom carried out, the practical results in human flight have remained very scanty up to the present day.

One can get a proper insight into the practice of flying only by actual flying experiments. The journey in the air without the use of the balloon is absolutely necessary in order to gain a judgment as to the actual requirements for an independent flight. It is in the air itself that we have to develop our knowledge of the stability of flight so that a safe and sure passage through the air may be obtained, and that one can finally land without destroying the apparatus. One must gain the knowl-

edge and the capacity needed for these things before he can occupy himself successfully with practical flying experiments.

As a rule the projectors and constructors of flying machines have not gathered this absolutely necessary practical experience, and have therefore wasted their efforts upon complicated and costly projects.

In free flight through the air a great many peculiar phenomena take place which the constructor never meets with elsewhere; in particular, those of the wind must be taken into consideration in the construction and in the employment of flying apparatus. The manner in which we have to meet the irregularities of the wind when soaring in the air can only be learnt by being in the air itself. At the same time it must be considered that one single blast of wind can destroy the apparatus and even the life of the person flying. This danger can only be avoided by becoming acquainted with the wind by constant and regular practice and by perfecting the apparatus so that we may achieve safe flight.

The only way which leads us to a quick development in human flight is a systematic and energetic practice in actual flying experiments. These experiments and exercises in flying must not only be carried out by scientists, but should also be practised by those wishing for an exciting amusement in the open air, so that the apparatus and the way of using it may by means of common use be quickly brought to the highest possible degree of perfection.

The question is therefore to find a method by which experiments in flying may be made without danger, and may at the same time be indulged in as an interesting amusement by sport-loving men.

Another condition is, that simple, easily constructed, and cheap apparatus should be used for such flying exercises, in order to conduce to a still more general participation in this sport.

All these conditions are easily fulfilled. One can fly long distances with quite simple apparatus without taxing one's

strength at all, and this kind of free and safe motion through the air affords greater pleasure than any other kind of sport.

From a raised starting point, particularly from the top of a flat hill, one can, after some practice, soar through the air, reaching the earth only after having gone a great distance.

For this purpose I have hitherto employed a sailing apparatus very like the outspread pinions of a soaring bird. It consists of a wooden frame covered with shirting (cotton-twill). The frame is taken hold of by the hands, the arms resting between cushions, thus supporting the body. The legs remain free for running and jumping. The steering in the air is brought about by changing the centre of gravity. This apparatus I had constructed with supporting surfaces of ten to twenty square metres. The larger sailing surfaces move in an incline of one to eight, so that one is enabled to fly eight times as far as the starting hill is high. The steering is facilitated by the rudder, which is firmly fastened behind in a horizontal and vertical position.

The machines weigh, according to their size, from 15 to 25 kilograms (33 to 55 lbs.).

In order to practise flying with these sailing surfaces one first takes short jumps on a somewhat inclined surface till he has accustomed himself to be borne by the air. Finally, he is able to sail over inclined surfaces as far as he wishes.

The supporting capacity of the air is felt, particularly if there is a breeze. A sudden increase in the wind causes a longer stoppage in the air, or one is raised to a still higher point.

The charm of such flight is indescribable, and there could not be a healthier motion or more exciting sport in the open air.

The rivalry in these exercises cannot but lead to a constant perfecting of the apparatus, the same as, for instance, is the case with bicycles. I speak from experience, for, although the system of my sailing apparatus remains the same, it has gone through numberless changes from year to year.[1]

The apparatus which I now employ for my flying exercises

[1] See article entitled " Wheeling and Flying."

contains a great many improvements as compared with the first sailing surfaces with which I commenced this kind of experiment five years ago. The first attempts in windy weather taught me that suitable steering surfaces would be needed to enable me to keep my course better against the wind. Repeated changes in the construction led to a kind of apparatus with which one can throw himself without danger from any height, reaching the earth safely after a long distance. The construction of the machine is such that it resembles in all its parts a strut-frame, the joints of which are calculated to stand pull and pressure, in order to combine the greatest strength with the least weight.

An important improvement was to arrange the apparatus for folding. All of my recent machines are so arranged that they can be taken through a door 2 metres high. The unfolding and putting together of the flying implements takes about two minutes.

A single grip of the hands is sufficient to attach the apparatus safely to the body, and one gets out of the apparatus just as quickly on landing. In case of a storm the flying-sail is folded up in half a minute and can be laid by anywhere. If one should not care to fold the apparatus, he may await the end of the storm under cover of the wings, which are capable of protecting twenty persons. Even the heaviest rain will not damage the apparatus. The flying apparatus, even if completely drenched, is soon dried by a few sailing flights after the rain stops, as the air passes through the same with great speed.

The latest improvements of the flying apparatus which I use for practical experiments refer to gaining of greater stability in windy weather.

My experiments tend particularly in two directions. On the one side I endeavor to carry my experiments in sailing through the air with immovable wings to this extent; I practise the overcoming of the wind in order to penetrate, if possible, into the secret of continued soaring flight. On the other hand I try to attain the dynamic flight by means of flapping the

wings, which are introduced as a simple addition to my sailing flights. The mechanical contrivances necessary for the latter, which can reach a certain perfection only by gradual development, do not allow yet of my making known any definite results. But I may state that since my sailing flights of last summer, I am on much more intimate terms with the wind.

What has prevented me till now from using winds of any strength for my sailing experiments, has been the danger of a violent fall through the air, if I should not succeed in retaining the apparatus in those positions by which one insures a gentle landing. The wildly rushing wind tries to dash about the free-floating body, and if the apparatus take up a position, if only for a short time, in which the wind strikes the flying surfaces from above, the flying body shoots downward like an arrow, and can be smashed to pieces before one succeeds in attaining a more favorable position in which the wind exercises a supporting effect. The stronger the wind blows, the easier this danger occurs, as the gusts of wind are so much the more irregular and violent.

As long as the commotion of the air is but slight, one does not require much practice to go quite long distances without danger. But the practice with strong winds is interesting and instructive, because one is at times supported quite by the wind alone. The size of the apparatus, however, unhappily limits us. We may not span the sailing-surfaces beyond a certain measure, if we do not wish to make it impossible to manage them in gusty weather. If the surfaces of 14 square metres [1] do not measure more than 7 metres [2] from point to point, we can eventually overcome moderate winds of about 7 metres [3] velocity, provided one is well practised. With an apparatus of this size it has happened to me that a sudden increase in the wind has taken me way up out of the usual course of flying, and has sometimes kept me for several seconds at one point of the air. It has happened in such a case, that I have been lifted vertically by a gust of wind from the top of the hill (shown in Fig. 3), floating for a time above the same at a height of about 5 metres, whence I then continued my flight, against the wind.

[1] About 150 sq. feet. [2] About 23 feet. [3] About 22 miles per hour.

Fig. 3.

Silberne Staatsmedaille. DEUTSCHES R PATENT Silberne Staatsmedaille. FÜR GEWERBLICHE LEISTUNGEN

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Herrn James Means.
Boston.

* * * * * * * * *

Des Englischen bin ich nicht genügend mächtig, um Ihr Werk eingehend zu studieren. Nachdem mir aber mein Bruder einige Artikel desselben übersetzt hat, habe ich den grossen Werth desselben erst eingesehen. Ganz vorzüglich finde ich Ihre Betrachtungen über die Analogie in der Entwickelung des Zweirades und der Flugapparate. Es wird mit den Flugapparaten ganz ebenso kommen. Man sollte aber von der Entwickelung der Zweiräder gelernt haben und die Entwickelung der Flugapparate mehr unterstützen, damit es nicht auch noch 100 Jahre dauert, bis wir wirklich fliegen.

Es grüßt ganz ergebenst

Otto Lilienthal

Although, while making these experiments I was thrown about by the wind quite violently and was made to execute quite a dance in the air in order to keep my balance, I yet was always enabled to effect a safe landing, but still I came to the conviction, that an increase in the size of the wings or the utilizing of still stronger winds which would lengthen the journey in the air, would necessitate something being done, to perfect the steering and to facilitate the management of the apparatus. This appeared to me to be all the more important as it is very necessary for the development of human flight that all, who take up such experiments, should quickly learn how to use the apparatus safely and understand how to use the same even if the air is disturbed. It is in the wind that this practice becomes so exciting and bears the character of a sport, for all the flights differ from each other and the adroitness of the sailing-man has the largest field for showing itself. Courage also and decision can be here shown in a high degree.

If such exercises are gone through with in a regular and approved method, they are not more dangerous than if one engages in riding, or sailing on the water.

Just as it is in sports on the water, so it is in sports in the air, that the greatest aim will be to reach the most startling results. The machines themselves, as well as the adroitness of their operators, will vie with each other.

He who succeeds in flying the farthest from a certain starting-point, will come forth from the contest as conqueror. This fact will necessarily lead to the production of more and more improved flying apparatus. In a short time we shall have improvements of which to-day we have not the faintest idea.

The foundation for such a development exists already; it only needs a more thorough carrying out to gain perfection. The greater the number is of such persons who have the furthering of flying and the perfecting of the flying apparatus at heart the quicker we shall succeed in reaching a perfect flight. It is therefore of paramount importance that as many physically and technically well-trained men as possible take interest in these

affairs, and that an apparatus be constructed which is as convenient and as cheap as possible.

The means by which I sought to facilitate the management of the machines and to increase their use in wind, consisted in the first place in different arrangements for changing the shape of the wings at will. I will, however, pass over the results here obtained as another principle gave surprisingly favorable results.

My experiments in sailing flight have accustomed me to bring about the steering by simply changing the centre of gravity.

The smaller the surface extension of the apparatus is, the better control I have over it, and yet if I employ smaller bearing surfaces in stronger winds, the results are not more favorable. The idea therefore occurred to me to apply two smaller surfaces, one above the other, which both have a lifting effect when sailing through the air. Thus the same result must follow which

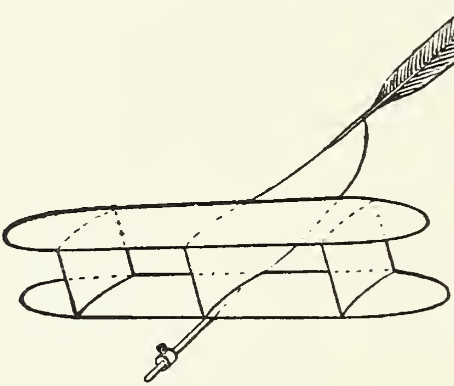

FIG. 1.

would be gained by a single surface of twice the bearing capacity, but on account of its small dimensions this apparatus obeys much better the changes of the centre of gravity.

Before I proceeded to construct these double-sailing machines, I made small models in paper after that system, in order to study the free movements in the air of such flying bodies and then to construct my apparatus on a large scale, depending on

the results thus obtained. The very first experiments with these small models, the form of which may be seen in Figs. 1

FIG 2.

and 2, surprised me greatly on account of the stability of their flight. It appears as if the arrangement of having one surface over the other had materially increased the safety and uniformity of the flight. As a rule it is rather difficult to produce models resembling birds, which, left to themselves, glide through the air from a higher point in uniformly inclined lines. I need only recall the extensive and expensive experiments made by Messrs. Riedinger, von Sigsfeld, and von Parsefal, of Augsburg, which showed the difficulty of constructing models that would automatically take up a course of stable flight. I myself doubted formerly very much that an inanimate body sailing quickly forward, could be well balanced in the air, and was all the better pleased in succeeding in this with my little double surfaces.

Relying on this experience I constructed first a double apparatus (Fig. 3), in which each surface contains 9 square metres.[1] I thus produced a comparatively large bearing surface of 18 square metres with but 5½ metres[2] span.

The upper surface is separated from the lower by a distance equal to three quarters of the breadth of the lower surface, and it has no disturbing influence whatever, but creates only a vertically acting lifting force. One must consider that with such an apparatus one always cuts the air quickly, so that both surfaces are met by the air-current, and therefore both act as lifters.

The whole management of such an apparatus is just the same as that of a single sailing surface. I could, therefore, use at once the skill I had already obtained.

The figures show how I change the centre of gravity, and

[1] About 97 sq. feet. [2] About 18 feet.

particularly the position of the legs in order to press down either wing. I retain the middle position, as shown in the frontispiece, whenever the apparatus floats horizontally.

The flights undertaken with such double sailing surfaces are distinguished by their great height, as is shown in Fig. 6, which gives a side-view of the apparatus.

The landing with this apparatus is brought about in the same way as with the single sailing surfaces by raising the apparatus in front somewhat and by lessening the speed, as shown in Fig. 7.

Fig. 8 shows an exact picture of the construction of the apparatus, as well as of the management of the same.

The energetic effect of the change of the centre of gravity and the safe starting of the apparatus obtained by it gave me courage to trust myself to a wind which at times exceeded a velocity of 10 metres (about 24 miles per hour).

This gave the most interesting results of all my practical flying experiments hitherto. Six or seven metres velocity of wind sufficed to enable the sailing surface of 18 square metres to carry me almost horizontally against the wind from the top of my hill without any starting jump. If the wind is stronger, I allow myself to be simply lifted from the point of the hill and to sail slowly towards the wind. The direction of the flight has, with strong wind, a strong upward tendency. I often reach positions in the air which are much higher than my starting-point. At the climax of such a line of flight I sometimes come to a standstill for some time, so that I am enabled while floating to speak with the gentlemen who wish to photograph me, regarding the best position for the photographing.[1]

At such times I feel plainly that I would remain floating if I leaned a little towards one side, described a circle and proceeded with the wind. The wind itself tends to bring this motion about, for my chief occupation in the air consists in preventing

[1] The photographs were made by Drs. Neuhaus and Fülleborn, who used a camera constructed by Dr. Neuhaus on the Stegemann principle.

Fig. 5.

Fig. 6.

a turn either to right or the left, and I know that the hill from which I started lies behind and underneath me, and that I might come into rough contact with it if I attempted circling. My endeavors tend therefore to remove myself farther from the hill either by increased wind or by flapping with the wings, so that I can follow the strongly lifting air-current in a circle, and so that I can have a sufficient space of air under and beside me to succeed in describing with safety a circling flight and to land finally steering against the wind.

As soon as I or any other experimenter succeeds in describing the first circling flight, one may regard this event as one of the most important conquests on the road to perfect flight. From this moment only, one is enabled to make a thorough use of the *vis viva* of the wind, so that when the wind increases one is able to steer against it, and when it decreases one can fly with it, getting beyond the same. One will feel here a similar effect, as already described by Professor Langley in his celebrated treatise entitled "The Internal Work of the Wind." It is no easy step from the theoretical conviction to the practical execution. The dexterity required to allow one's self to be borne by the wind alone, by describing well-directed circles, is only understood by those who are well acquainted with the difficulties one encounters with the wind. And yet all that may be acquired by practice. When the time comes that athletic associations emulate each other, such results will not be long in following.

Moreover, experimenters will proceed from simple floating and sailing, which in any case form the foundation for practical flight, by degrees to flying with movable implements. As one is enabled to balance himself for some time in the air, the foundations for more extended dynamic effects are easily and safely attained. The different projects may be easily tried by adding the motor work to the simple sailing flight taken as a basis. In this manner one will soon find out the best methods; for practical experience in the air is far better than figuring on paper.

The only thing which may cause difficulties is the procuring of a suitable place for practising.

Just as the starting from the earth is rather difficult for larger birds, the human body, being still heavier, meets with peculiar difficulties at the first flight upward. The larger birds take a running start against the wind or throw themselves into the air from elevated points, in order to obtain free use of their pinions. As soon, however, as they float in the air, their flight, which was begun under special difficulties, is easily continued. The case is similar in human flight. The principal difficulty is the launching into the air, and that will always necessitate special preparations. A man will also have to take a running start against the wind with his flying apparatus, but on a horizontal surface even that will not be sufficient to free himself from the earth. But, on taking a running start from a correspondingly inclined surface, it is easy to begin one's flight even if there is no wind.

According to the example of birds, man will have to start against the wind; but as an inclined surface is necessary for this he needs a hill having the shape of a flat cone, from the top of which he may take starts against the wind in any direction.

Such a place is absolutely necessary, if one wishes to make flying experiments in a convenient way without being dependent on the direction of the wind.

For this purpose I have had an artificial hill, 15 metres high, erected near my house in Gross Lichterfelde, near Berlin, and so have been enabled to make numerous experiments. The drawings show this hill, or part of the same, from the outside. Fig. 9 represents a section of it, showing the cavity in the top intended for keeping the apparatus. At the same time the line of flight taken in calm weather is shown by dotted lines.

If a place for this sport is procured where young persons wishing to indulge in flight can disport themselves in the air, they will then have a chance to make instructive and interesting sailing flights, and I should advise having the hill twice as high, and to form it according to Fig. 10, so that one can commence the flights from a height of 30 metres. The cavity inside should be large enough to hold several complete machines.

Fig. 7.

Fig. 8.

From such a hill one can take flight of 200 metres distance, and the floating through the air on such long distances affords indescribable pleasure. Added to which this highly exciting exercise is not dangerous, as one can effect a safe landing at any time.

Such a place in which young men can practise sailing flights and can at times make motor experiments with the wings would prove to be of great interest, both to those participating and to the public in general.

And when, from time to time, competitive flights were arranged, we should soon have a national amusement in this as in other sports which we have already. One can see even now that the pleasure and interest of the public in such races, when the gymnasts skilled in flights, shoot through the air, would be greater and more intense than, for instance, in horse or boat racing. The air is the freest element; it admits of the most unfettered movement, and the motion through it affords the greatest delight not only to the person flying, but also to those looking on. It is with astonishment and admiration that we follow the air gymnast swinging himself from trapeze to trapeze; but what are these tiny springs as compared to the powerful bound which the sailer in the air is able to take from the top of the hill, and which carries him over the ground for hundreds of yards?

If the atmosphere is undisturbed, the experimenter sails with uniform speed; as soon, however, as even a slight breeze springs up, the course of the flight becomes irregular, as indicated in Fig. 10. The apparatus inclines now to the right, now to the left.

The person flying ascends from the usual line of flight, and, borne by the wind, suddenly remains floating at a point high up in the air; the on-lookers hold their breath; all at once cheers are heard, the sailer proceeds and glides amid the joyful exclamations of the multitude in a graceful curve back again to the earth.

Can any sport be more exciting than flying? Strength and adroitness, courage and decision, can nowhere gain such tri-

umphs as in these gigantic bounds into the air, when the gymnast safely steers his soaring machine house-high over the heads of the spectators.

That the danger here is easily avoided when one practises in a reasonable way, I have sufficiently proved, as I myself have made thousands of experiments within the last five years, and have had no accidents whatever, a few scratches excepted.

But all this is only a means to the end; our aim remains — the developing of human flight to as high a standard as possible. If we can succeed in enticing to the hill the young men who to-day make use of the bicycle and the boat to strengthen their nerves and muscle, so that, borne by their wings, they may glide through the air, we shall then have directed the development of human flight into a course which leads towards perfection.

Plate V.

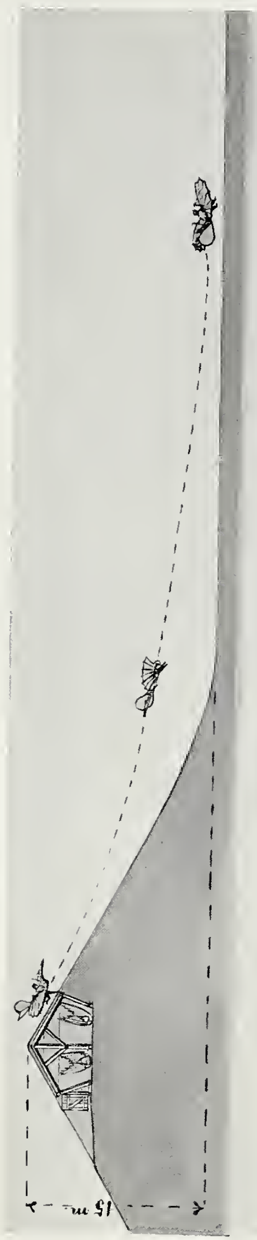

Fig. 9.

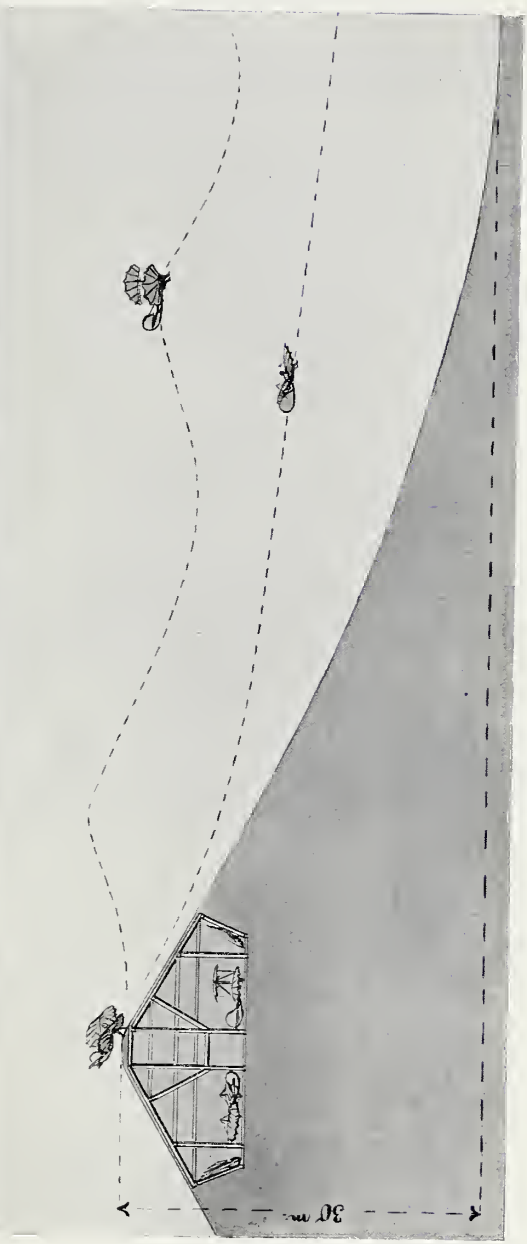

Fig. 10.

[From Aero. Ann., 1896.]

WHEELING AND FLYING.

By the Editor.

THE slow development of the flying machine in its early stages finds its analogue in that of the bicycle. The admirable wheel of to-day is the product of more than eighty years of careful thought and experiment.

The machine has been improved very gradually; most of the modifications have been slight; yet some of the stages have been marked with great distinctness.

The twelve machines here shown in the drawings give a rough outline of the progress made. First, we have the wheel of 1816 (Fig. 1), propelled by striking the feet against the ground. This machine represents the parent form, involving the great principle of two wheels balanced by the act of turning the forward wheel on a pivot. It was used principally for the purposes of sport, and it is easily seen that it was at its best on down grades.

Looking backward, it seems strange to us that a device so simple as a pair of foot cranks attached to the front axle was not soon adopted, yet the discovery of such simple things sometimes takes years of hard thinking. Columbus was doubtless surprised when the superficial people of his day told him on his return that any sailor might have discovered the distant land, "all one had to do was to sail west." His alleged reply, illustrated by the balancing of the egg, was most appropriate. The inventor of the sewing machine informed the world that all through the centuries the sewing needle had been threaded at the wrong end; no one knows how long it took him to think that out. We do know, however, in the case of the wheel, that it took many years to think of putting foot cranks on the front axle.

Mr. Porter says[1] that in 1821 Gompertz invented the "Hobby Horse" shown in Fig. 2, and that in 1840 McMillan made a rear-driving machine as shown in Fig. 3.

He quotes M. de Saunier as saying that the honors of first applying foot cranks to the front axle seem to be evenly divided between Michaux and Lallement, who probably worked independently of each other, the former applying the cranks in 1855, the latter in 1863.

Lallement's machine of 1866 is shown in Fig. 4. This was the machine which immediately preceded the velocipede excitement of the late sixties.

Fig. 5 shows the improvement made from 1866 to 1869.

Mr. Porter says, "In 1871 W. H. J. Grant proposed the use of rubber pedals, . . . and he also vulcanized rubber tires into crescent-shaped metal rims."

"In 1873 there was produced by Starley, 'the Father of the Bicycle,' about the first machine (Fig. 6) embodying most of the features which are found in the modern Ordinary."

The Ordinary was greatly improved in the ten or twelve succeeding years (see Fig. 7), and long distance riding became common, yet the dangers attending the use of the high machine gradually led to the designing of lower wheels, of which types are shown in Figs. 8, 9, 10, and 11.

Later came the safety with cushion tires, which was followed, at last, by the pneumatic Safety of to-day (Fig. 12). This is a mere outline; the intermediate machines were many.

It is not uncommon for the cyclist, in the first flush of enthusiasm which quickly follows the unpleasantness of taming the steel steed, to remark, "Wheeling is just like flying!" This is true in more ways than one. Let us note the points of resemblance. Both modes of travel are riding upon the air, though in one case a small quantity of air is carried in a bag and in the other the air is unbagged. There are many who

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[1] See *Wheels and Wheeling*, by Luther H. Porter. Published by The Wheelman Co., 12 Pearl st., Boston. 387 pp. 75 cents. The editor of The Annual is indebted to the author of the above interesting and valuable work for the principal facts concerning bicycles mentioned in this article. The cuts 1 to 11 are taken from Mr. Porter's book, he having kindly consented to their reproduction.


Fig. 1.
CELERIPEDE.
1816.

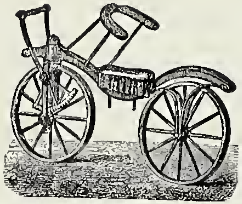
Fig. 2.
HOBBY-HORSE.
1821.

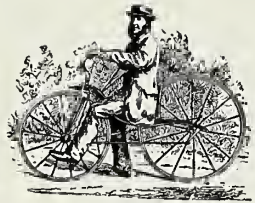
Fig. 3.
McCALL'S COPY OF
McMILLAN'S REAR-DRIVER.
1840.

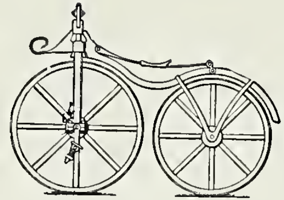
Fig. 4.
LALLEMENT'S VELOCIPEDE.
1866.

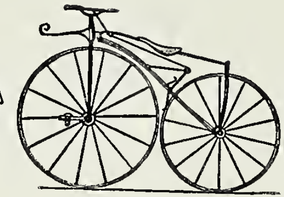
Fig. 5.
AMERICAN VELOCIPEDE.
1869.


Fig. 6.
ARIEL BICYCLE.
1873.


Fig. 7.
"ORDINARY" BICYCLE.
1886.

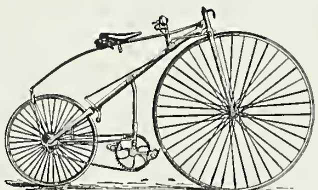
Fig. 8.
BICYCLETTE.
1880.


Fig. 9.
KANGAROO SAFETY.
1883.


Fig. 10.
MARVEL SAFETY.
1884.

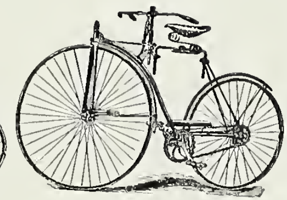
Fig. 11.
ORIGINAL ROVER SAFETY.
1884.

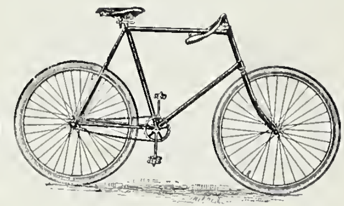
Fig. 12.
PNEUMATIC SAFETY.
1896.

THE DEVELOPMENT OF THE WHEEL.

believe that in order to travel upon air it is not necessary to put the air in a bag; they not only believe this but they know it has been done. Lilienthal has done it many times, and the Lilienthal machine is to flying, what the wheel of 1816 was to pneumatic wheeling. The Lilienthal machine seems likely to lead to important things, yet there are men who say of the inventor: " He cannot fly up, he can only fly down, he is a parachutist, a flying squirrel, he has not solved the great problem." True, he has not solved it, but he has given a partial solution which will place his name on the roll of the immortals.

It is not unlikely that men regarded the wheel of 1816 as some now regard the Lilienthal soarer. They probably said, "This machine will do for coasting down hill, but that is not practical travelling. You cannot climb hills with the thing; it is not of much importance anyhow." But after a while, one day a man who thought put cranks on that machine!

Lilienthal flies not only down, but also up. His course as a whole is downward, but when under favoring winds he gets energy from beneath he rises. The only reason that his course as a whole is not upward is that he has not yet completed his apparatus for giving constant energy.

That will take time, and if the world is to make rapid progress in manflight it must have a much greater confidence in the value and importance of the Lilienthal soarer than it had in the wonderful balancing wheel of 1816. It was a balancing wheel, and the great art of balancing began with it. To learn to wheel one must learn to balance; to learn to fly one must learn to balance. Why not begin now, instead of imitating the human race of the first half of the century which took so many years to get its feet off the ground?

[From AERO. ANN., 1897.]

OUR TEACHERS IN SAILING FLIGHT.

BY OTTO LILIENTHAL.

Translated from Prometheus.

I HAVE recently seen such wondrous feats performed in sailing flight that, as I now sit at my table to write, I do so with more enthusiasm than ever before; for the things which I have seen prove clearly and definitely that flight must be much easier than it is generally believed to be, if we only, with suitable wings, boldly trust ourselves to the wind. All perplexities concerning light motors, and speculations on the amount of power required for flying, are relegated to the background by the fact that the power of the wind alone is sufficient to effect any kind of independent flight.

If we had not those magnificent models in flying, those large and heavy birds which, without a flap of the wing, allow themselves to be borne by the wind, doubters would be justified, and we should lack the courage to attempt the solution of the problem with the perseverance which is necessary; but, as it is, the tangible results cannot be denied, there is a flight which does not require any effort, where only the shape and position of the wings must be right in order to float, circle, or sail in the air at any height or in any direction desired; therefore our confidence, notwithstanding many vain attempts, is always renewed.

But which are the birds best fitted as models in soaring flight? How can we best find a position for making fruitful observations?

If we go through the fields in summer, we see now and then a bird of prey circling about; then a swamp bird, of the larger kind, passing along arrests our attention: yet if one goes out on purpose for such observations, it may be that he will lie in

wait for days in vain, or if a sailing bird comes in sight, it is very likely high up in the heavens and far away, so that little can be learned from it.

The Americans are proud of their buzzard which gives them such exhibitions in the art of soaring, but in order to observe this near at hand and to be able to study the effect of soaring, places of concealment must be arranged in the tops of trees and in rocks from which the observer may watch the motions of flight.

Things are easier for people living on the coast; the graceful soaring flight of the gulls can be frequently observed near at hand, as these birds are not very timid, from their being so seldom hunted. But the best opportunity for studying soaring flight is to be had in the lowlands of Northern Germany, in the villages, where the stork lives his family life on the low roofs, unconcernedly showing off his art close above the heads of observers, and by his size giving the observer the clearest impressions of the shape and position of the wings.

But even at these stork nests it is tedious to wait for the moment when the old birds return with food for their young; it is generally only for a short moment, in the quick coming and going, that one can observe closely the flying or the soaring stork.

Observation is more productive when the young birds are fledging. As soon, however, as they have learned to soar, which soon happens in windy weather, they do not remain in the vicinity of the nest, and one can look for them a long time in vain.

Being convinced that Father Longlegs is just made for our instructor in flying, I kept a great many young storks some years ago, whose attempts at flying have given me many explanations in flying technics. As soon, however, as their proficiency extended to soaring, when rising above the tree-tops, they felt the magnificent bearing-effect of the wind, and ventured into higher regions, they joined other wild storks, and so ended all further observation.

While on a journey to procure these young storks a friendly man told me that there could be no better place for observing

these birds than the village of Vehlin, near Glöwen, on the Berlin-Hamburg railroad, for there there were on every roof two or three stork nests, and hundreds of storks circled above them.

This address slumbered, probably, seven years in my note-book, till last Easter I made use of the fine days to take a trip, in company with my two boys, to Vehlin. The road — a two hours' walk — from the station of Glöwen led us through villages in no way distinguished by a wealth of storks. I began to think the good man had played us a joke. But on approaching the village of Vehlin, my two boys cried out, "Why, there is a stork's nest!" "There's another!" "And another!" "There are two on one roof!" "Yonder are two more!" Our friendly adviser was quite right, for on the forty houses of this little village were no less than fifty-four storks' nests, about some of which the single pairs were yet fighting, while in some the process of hatching had already commenced.

With the exception of an interesting combat between the male storks which, rolled up like a ball, often rolled off the roof, only separating in a fright on dropping into the yard, there was not much to be seen that day. Yet I was glad to know of a place where in mid-summer, when the young storks are fully grown, the most magnificent exercises in flying would be observable. I was not mistaken. On going again to Vehlin in August, almost the entire army of storks was to be seen in the air over the village. The day was sunny and windy, just suitable for studying the soaring of these immense birds.

My observations result, so far, in ascertaining that in windy weather, when the air in the lower strata has a velocity of about six to eight metres, the stork does not move its wings at all, and proceeds soaring or sailing in the air.

This soaring took place not only close above the roofs of the houses, but also at so great a height that it was difficult to follow the birds' motion with the naked eye. The birds flapped their wings only when moving between the houses or trees — that is, in places protected from the wind. They soared in any direction they pleased, against the wind, with the wind, or side-

wise. They circled in order to ascend quickly to higher air strata.

When instructing their young the storks fly mostly in smaller or larger companies, at different heights, flying over the village alternately with or against the wind. In some of the nests young birds were standing, which did not yet take part in the exercises. As soon as these latter saw their relatives fly away above them they would greet them in their own peculiar language, by laying their heads on their backs and rattling with their beaks. Generally some of those flying would descend from the rest to their young ones in the nest. If the flight in doing this had to be made from a great, windy height, it gave the impression that the stork found the descent more trying than the ascent.

To descend more rapidly the stork employs various manœuvres. The simplest is that of letting the legs hang, thus lessening the soaring effect by a resistance to the air. With a good sailing-wind, however, these means are insufficient, and head and neck have to be lowered, at the same time the wings are bent so low down as to form the perfect shape of a bell. This position, however, appears to cause the stork an effort, as it soon changes again to the outspread position. On attaining this, however, it again commences to ascend, and then it is seen, after a few vain efforts to come down quickly from the height, to employ a radical means for rapid descent. This consists of placing itself in a vertical plane; that is, with the point of one wing underneath, the point of the other above. In this manner it can, of course, shoot downwards like an arrow. In its downward rush, however, it changes several times from the right position to the left. Finally it takes once more the position of the bell, till it lands on the nests, where it is always received, after such feats of prowess, with a joyful rattle.

A good deal could be said about these drops, often from a height of several hundred metres, but we have less interest in the descent from the height than in the art of balancing in the air simply by means of outspread wings.

In order to observe this proficiency frequently close to, we

chose a point of observation on a farm which was blest with five stork-nests, and from where we could oversee a dozen others.

The only means of lifting the last veil from the mystery of soaring is to be able to frequently observe large birds at a near distance in their soaring flight.

Three things are essential for soaring: a correct shape of wing, the right position of wing, and a suitable wind. In order to judge of these three factors and their changeable effect, we have nothing but our practised eye to depend upon.

Just how much the cross-section of the wing is arched when the stork is resting on the wind can be determined only by eye measurement; similarly the position of the wing to the direction of the wind and to the horizon. But when hundreds of storks give one the opportunity to observe the same in clear weather close at hand, what is seen is impressed so indelibly on the mind that it enables one to draw correct conclusions as to the existing laws.

In general, one can say that when the stork flies with wings spread horizontally and allows itself to be borne by the wind alone, it is but seldom that a stronger gust of wind causes the stork to draw in its wings.

The parabolic profile of the wings has a depth which I consider to be about $\frac{1}{20}$ of the breadth of the wing. The pinions are mostly spread out, but do not lie in one plane; but the more they are to the front, the higher are the points, certainly because they would otherwise hinder one another in their bearing capacity.

When in this position the stork passes slowly against the wind above the observer, the head and neck are, as a rule, stretched straight out; but if one imagines that soaring is possible in this position, that it causes little resistance, he will be surprised to see a stork, sailing in this manner, suddenly, without changing its position, lay its head back and rattle joyously. While we human beings are striving to find the proper shape for the wings, building theory on theory, flying takes place in nature in a wondrously simple way, quite as a matter of course.

It is ever with a large surplus of flying capacity that nature has equipped her subjects. A stork which has lost some of its largest pinions does not for that reason sail less gracefully than its comrades.

Storks are not particular in the way they hold their pointed beaks and long necks, as has been observed already. One after the other sailed over our heads; one held itself to one side, the other kept to the other side, without any change in their flight. Here comes another one very slowly against the wind; just as it stands over our heads it bends its head to the left to take a minute survey of its wings, on which it puts its head quite to one side and begins in a most leisurely way to put the feathers on its left wing in order with its beak; meanwhile its graceful sailing-flight does not suffer the slightest interruption. We looked at one another surprised by this sight, as if we would say, "That is beyond everything! For thousands of years we human beings have racked our brains to unravel the mysteries of flight, and we feel happy when we drink mere drops from the Fount of Knowledge, and here the storks seem to run riot in the art of flying, as if nothing in the world were easier." [1]

Afterwards I found out that a stork, putting beak, head, and neck back quite to the left, certainly changes the left wing a good deal more, but that, in this position, wherein head and neck are directly in front of the arm of the wing, to a certain extent a broadening of the left wing and therefore an increase in the bearing capacity of the same takes place.

One might therefore not be at all surprised if the balance in soaring be not disturbed. The young storks, which are known by their gray legs, betray themselves also in the air by their less sure flight; in soaring they are sometimes thrown here and there by the wind, and therefore take more frequently to flapping their wings than their red-legged parents, which understand in a masterly way how to meet every gust of wind.

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[1] Wir Menschen quälen uns seit Jahrtausenden, hinter die Räthsel des Fluges zu kommen und sind schon froh, wenn wir tropfenweise aus dem Born der Erkenntniss schöpfen können, und hier wird von den Störchen in einer Weise mit dem Flugvermögen gewuchert, als gäbe es in aller Welt nichts Leichteres als das Fliegen.

Whoever observes minutely a stork, which is proficient in flying, sailing along at a moderate height, will notice a limited but almost uninterrupted turning and moving of the wings which apparently serve to exactly meet the pressure of the wind. Our eyes are riveted with admiration and wonder on each of these birds as they pass along. They skim and sail in the air, and their bodies, weighing four to five kilograms, appear to be borne by a magic power. Their whole behavior indicates that a flight like this is no labor, but rather akin to resting; their tameness lets them pass close to us; we can recognize each feather of their outspread wings. All deception as to the real cause of sailing flight appears excluded. That which is possible to these storks must also be possible to any other similarly formed flying body.

As the little swallow, which just now sails over the farm-yard through the broken window into the cow-shed, understands soaring on the same principles as the stork, so must, on the other hand, a larger apparatus, capable of bearing up a man, be able to sail on the wind, if it be of the right shape.

Of course such an apparatus alone cannot equip us for flying; the capability of using it, which is inborn with the stork, must be gained by us by laborious training, but even in this we can trust ourselves fully to our long-legged instructor. It shows us with what facility one can change the irregular blowing of the wind into bearing-power, provided we have the necessary practice. When the stork sails over the roofs of the houses one can see how it applies every gust in the air to its advantage. The higher it circles, the more tranquil and certain its flight becomes in proportion to the increasing uniformity of the wind.

A particularly fine spectacle is a stork remaining for a great length of time floating (remaining stationary) at one point in the air. This feat also, where all the forces are equally balanced, I saw performed by older storks only. These masters in the art of flying understand how to keep their position at one point even in high winds, as well as to shoot along with high velocity, all of which they perform by careful adjustment of their outspread wings.

The simplicity of the instruments with which nature obtains these wonderful effects in flying gives us hope that we shall come to a satisfactory solution of the problem.

Whoever needs incentive to labor with zeal ought to look up the little village of Vehlin in Ostprignitz in mid-summer, when the magnificent birds in their fine black and white garments sail majestically overhead, and are seen against the blue of heaven like emblems of liberty.

[From Aero. Ann., 1897.]

AT RHINOW.

[The following is a translation of an extract from an article by Lilienthal in *Zeitschrift für Luftschiffahrt*, March, 1895.]

Lilienthal writes thus of the extreme care needed in making changes in an air-sailing machine:

My neglect of this circumstance I once came near paying dearly for. The winter before last I constructed several machines, the sustaining surfaces of which had an exact parabolic profile which almost coincided with the arc of a circle. The holding point for the hands and arms I placed in such a manner that the centre of gravity of the body was, on the average, situated one-tenth of the width of the wing in front of the centre of the surface. In my experiments made before Easter from the still higher mountains near Rhinow, I perceived that I had to bear with the upper part of my body a good deal towards the back to prevent my shooting forward in the air with the apparatus. During a gliding flight taken from a great height this was the cause of my coming into a position with my arms outstretched, in which the centre of gravity lay too much to the back; at the same time I was unable — owing to fatigue — to draw the upper part of my body again towards the front. As I was then sailing at the height of about 65 feet with a velocity of about 35 miles per hour, the apparatus, overloaded in the rear, rose more and more, and finally shot, by means of its *vis viva*, vertically upwards. I gripped tight hold, seeing nothing but the blue sky and little white clouds above me, and so awaited the moment when the apparatus would capsize backwards, possibly ending my sailing attempts forever. Suddenly, however, the apparatus stopped in its ascent, and, going backward again in a downward direction, described a short circle and steered with the rear part again upwards, owing to the horizontal tail which had an upward slant; then the machine turned bottom upwards

and rushed with me vertically towards the earth from a height of about 65 feet. With my senses quite clear, my arms and my head forward, still holding the apparatus firmly with my hands, I fell towards a greensward; a shock, a crash, and I lay with the apparatus on the ground.

A flesh wound at the left side of the head, caused by my striking the frame of the apparatus, and a spraining of the left hand, were the only bad effects of this accident. The apparatus was, strange to say, quite uninjured. I myself, as well as my sailing implements, had been saved by means of the elastic recoil-bar, which, as good luck would have it, I had attached for the first time at the front part of the apparatus. This recoil-bar, made of willow wood, was broken to splinters; it had penetrated a foot deep into the earth, so that it could only be removed with difficulty. I describe this accident so minutely because it is probably the worst which could happen in sailing flight; I wish to say that this is not the accident which gained publicity through the press, and which was the cause of a correspondence from all countries. The only outside spectators of this fall were the little girls and boys of the Stöllner schools, who had had vacation, and were looking on with their teachers at my experiments from the ridge of the mountain.

My brother, who also took part in these experiments and had been able to get a perfect side-view of my unsuccessful flight, said it had looked as if a piece of paper had been sailing about in the air at random. In my thousands of experiments this is the only fall of that kind, and this I could have avoided if I had been more careful.

If one uses the necessary precautions when making the experiments, any great danger is, strictly speaking, excluded. The use of a recoil-bar is, of course, always advisable.

In the very slight accident which a reporter who happened to be present brought into the papers in a greatly exaggerated and incorrect way, the elastic impact of the recoil-bar proved to be excellent. In this experiment a change in the curve of the surfaces came into account. I was occupied in testing wings of the strongest possible curves to make compara-

tive experiments regarding the influence of the amount of concavity on the bearing capacity. I had already taken several successful flights with an apparatus the concavity of which was a little over $\frac{1}{12}$ of the breadth of the wing; then while sailing, the apparatus was pressed down in front by a wind from above, in the middle of the course of flight, by means of which it was run to the ground.

With these strongly curved profiles the danger is, that the surface being strongly inclined, the front receives some pressure of the air from above in consequence of sudden changes in the wind, and this would, of course, greatly diminish the stability of the flight. As has already been observed, it is not advisable to extend the height of the profile beyond $\frac{1}{12}$ of the breadth of the wings, in spite of the excellent sustaining qualities which may so be obtained.

One can produce very safe working qualities with strong power of sustentation with a height of profile between $\frac{1}{18}$ and $\frac{1}{15}$ of the breadth of the wing.

As a matter of course, the more one penetrates into the details of the technics of flight the more varied the points of view will become. This is the case even with simple sailing flights which demand only a simple sustaining surface. How much more this will be the case in dynamic flight! I have had already enough impressions as to that. But of this some other time.

[From AERO. ANN., 1897.]

THE BEST SHAPES FOR WINGS.

BY OTTO LILIENTHAL.

[Abridged translation from *Zeitschrift für Luftschiffahrt*, XIV. Jahrgang, Heft 10.]

THE results which we reach by practical flying experiments will depend most of all upon the shapes which we give to the wings used in experimenting.

Therefore there is probably no more important subject in the technics of flying than that which refers to wing formation.

The primitive idea that the desired effects could be produced by means of flat wings has now been abandoned, for we know that the curvature of birds' wings gives extraordinary advantages in flying.

The experiments on the resistance of air to curved surfaces have shown that even very slight curvatures of the wing-profile increase considerably the sustaining power, and thereby diminish the amount of power required in flight.

The wing of a bird is excellent not only because of the curvature of its cross-section, but the rest of its structure and formation also has influence upon the flight. Therefore the outline of the wing is certainly of importance.

It is probable that the form of the cross-section of the wing and flight-feathers (*Schwungfedern*) has a favorable influence upon the flight.

Experiments have not yet been made to show conclusively whether or not the feather structure of a wing endows it with a special quality whereby the sustaining power is increased. With investigators this has been a subject of conjecture. Therefore it is questionable (*auch fraglich*) whether we are wrong if, in constructing flying apparatus, we keep to the bat's wing, which is easier to construct.

Bats fly much better than is generally thought. Two early

bats, which I saw flying this summer in broad sunshine and in somewhat windy weather, sailed along so well without flapping their wings that I thought, at first, they were swallows. Of course on evenings when there is no wind, the bat must flutter continually. The early-flying bat is also called evening-sailer (*Abendsegler*) which indicates that its sailing flight has been marked.

The most important point as regards the form of the wing will always be the curvature of its profile. If we examine any bird's wing we find that the enclosed bones cause a decided thickening at the forward edge. The question now is, What part does this thickening play in the action of the curved surface? The thickening is quite considerable, particularly in birds which have long, narrow wings. An albatross in my possession has a breadth of wing 16 centimetres, the thickened part of which measures 2 centimetres; the thickness is therefore $\frac{1}{8}$ of the breadth of the wing. As the albatross is one of the best sailers, we can scarcely assume that the comparatively great thickness of the wing at its outer edge has a detrimental effect upon the bird's flight.

For a long time I have assumed that the thickening which all birds' wings have at the front edge produces a favorable effect in sailing flight.

. . . .

By means of free-sailing models I have now learned that nature makes a virtue of necessity, that the thickened front edge is not only harmless, but in sailing flight is helpful (*sondern den Schwebe-effect nicht unerheblich erhöht*).

The experiments are easily tried. It is only necessary to make a number of models of equal size and weight, each one having a different curve in its sustaining surfaces. These models I make of strong drawing paper, the size of the surfaces being about 4 inches in width by 20 inches in length.[1]

The experimenter can let these models sail from any tower or roof in front of which there is an open space. Each model must be made to glide through the air many times until it

[1] Drawings of these models will be found on pp. 14 and 15, Aeronautical Annual, No. 2.

reaches the ground. Experiments must be made in the stillest possible air.

The lengths of flights are all noted down, and from a long series of experiments the arithmetical mean for each design is computed. The models having the best profiles will make the longest flights. In this way a reliable table can be made which will show the relative merits of the profiles, and will also show quite plainly in which direction the most useful form will have to be developed.

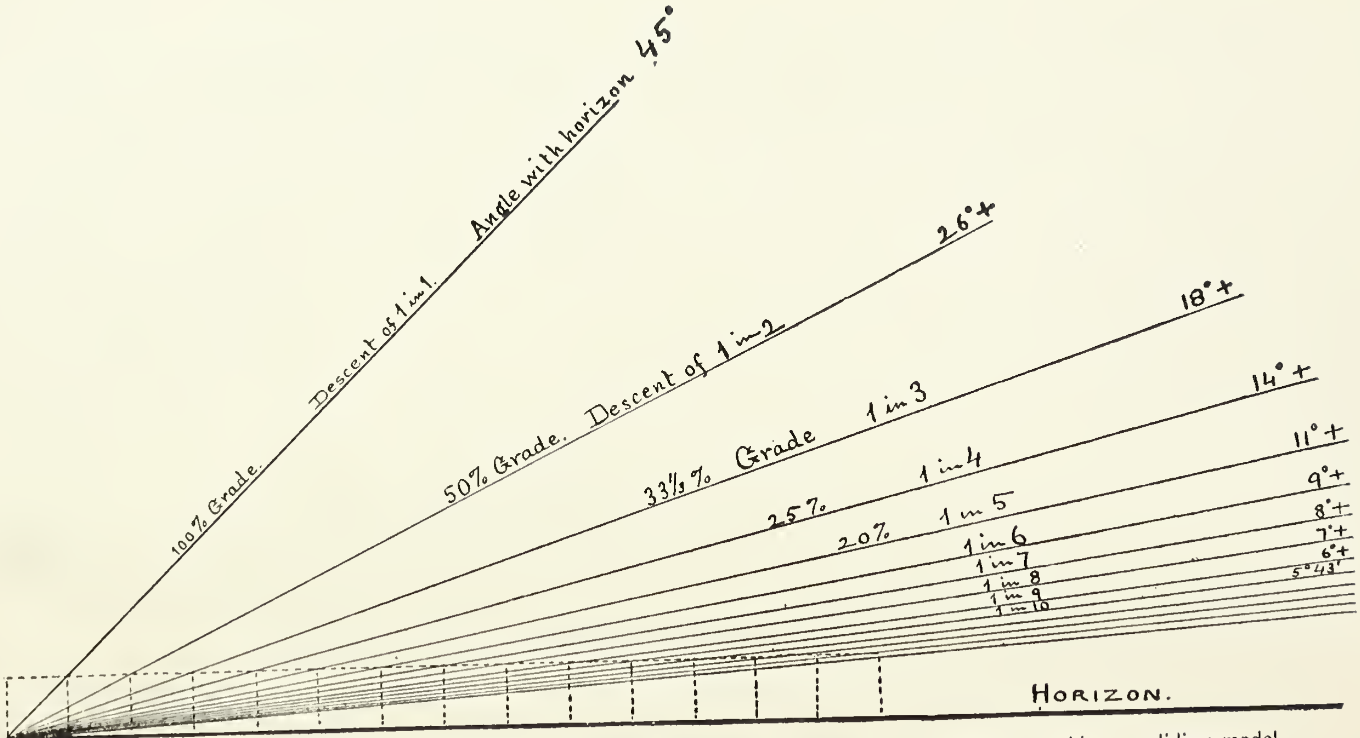
Until now I have endeavored to find out the best proportions for wings by constructing different kinds of sailing apparatus. In this way, of course, many important facts have been ascertained. The construction of full-sized apparatus requires a great deal of time and is expensive, therefore we must welcome a method which permits inquiry into the forms of wings in models which fly automatically. Besides that, it is not every one's business to throw himself into space in a sailing apparatus, although he who would succeed in practical flying can scarcely avoid this way.

Considering the fact that the most important thing is to ascertain what are the best qualities of the natural wing,— which is in every respect perfect,— these steadily sailing models offer every one an opportunity of engaging in experiments of this kind. Further, any one who takes up this kind of experiment will find great pleasure in watching the manœuvres of his small flyers, which often vie with the best sailers among birds. I can therefore recommend this occupation not only for the furthering of the science of mechanical flight, but also because it affords a most interesting pastime.

The few measurements made so far by this method are too incomplete to be fit, as yet, for publication. I am preparing, however, a systematic series of experiments, the results of which will be stated when the experiments are finished.

Meanwhile, I cherish the hope that this paper may be an incentive to others to make similar experiments, so that we may sooner reach the desired end.

NOTE.— This is a part of Lilienthal's unfinished work, which it is to be hoped will be taken up by many. The fact that he thought it well worth doing is significant.— ED.



The above diagram is intended to assist the eye in judging the angle of descent of an air-sailing machine or gliding model.

[From AERO. ANN., 1897.]

OTTO LILIENTHAL.

A MEMORIAL ADDRESS DELIVERED BEFORE THE *DEUTSCHEN VEREIN ZUR FÖRDERUNG DER LUFTSCHIFFAHRT, NOVEMBER 26, 1896.*

BY KARL MÜLLENHOFF.

[Translated from *Zeitschrift für Luftschiffahrt.*]

THE irreparable loss which our Society has sustained in the death of Otto Lilienthal is still fresh in our memories. We all remember distinctly the untiring character of him who united the definiteness of aim which characterizes manhood with all the ardor and enthusiasm of youth.

For a long time, more than ten years in fact, Lilienthal was a member of our Society, and only a few of our oldest members can remember the whole of the energy which he devoted to our work. This is why I, who introduced Lilienthal into the Society, will endeavor to show what his membership really meant; all the more so, as it was I especially who was fortunate enough during the many years of mutual intercourse to really know the depths of this noble character and to learn to appreciate it. During this long period I had the good fortune to be initiated into all the phases of his studies of the problem of manflight.

Otto Lilienthal was born May 24th, 1848, at Anclam in Pomerania. Up to his sixteenth year he went to the Latin High School of his native city; in 1864 he entered the Potsdam Technical School; after graduation from this institution in 1866 he began the study of civil engineering by a one year's practical course in Schwartzkopf's machine shops. From 1867 to 1870 he was a student at the Berlin Technical Academy, and he had just been graduated from that academy when, in the summer of 1870, the beginning of the Franco-Prussian war called him into the service.

He served as volunteer in the Fusileer Infantry Regiment of the Guards, and was with that regiment at the siege of Paris. After the campaign was over he took a place as civil engineer in Weber's machine shops at Berlin, and was afterwards, from 1872 to 1880, engaged in the large machine shops of C. Hoppe, of Berlin.

In 1880 he started a machine factory of his own, and succeeded, in the course of time, in bringing it to a flourishing condition by his energy and inventive powers.

The products of his machine shops were of great variety. One of his inventions was the construction of light steam motors with serpentine pipes. He also made a specialty of marine signals. His achievements in these procured for him the silver State medal. The fog-horn which could be heard during the time of the Berlin trade exhibition near the Imperial ship was constructed and exhibited by him.

From his earliest youth he had been much interested in the subject of manflight, and as early as 1861, being only thirteen years of age, he began to make practical flying experiments, together with his younger brother Gustavus. The first wings made by the two brothers consisted of light flaps which were fastened to the arms; with these they attempted running downhill. The experiments were mostly made at night by moonlight, the young flying artists being naturally afraid of the teasing of their school-fellows.

The experiments which had been started in Anclam were continued in Potsdam. The two brothers constructed wings which were fastened to the back, and which moved up and down by throwing out the legs as in swimming. In 1867 and 1868 while in college, Lilienthal constructed a more complicated apparatus. In these experiments also his brother Gustavus took an active part.

The experiments interrupted in consequence of the campaign were taken up again as early as the autumn of 1871.

Lilienthal had seen that the negative results of previous flying experiments could be traced to the fact that it had been the custom to attempt the solution of the problem of birds'

OTTO LILIENTHAL.

Born 1848. Died 1896.

"For thousands of years we human beings have racked our brains to unravel the mysteries of flight, and we feel happy when we drink mere drops from the Fount of Knowledge, and here the storks seem to run riot in the art of flying, as if nothing in the world were easier."

flight trusting only to incomplete and even sometimes erroneous observations; or else to undertake the task of deriving the laws of the mechanics of flight purely theoretically without resorting to any observations at all.

Both methods would naturally lead to erroneous results. Lilienthal concluded to investigate the whole subject by means of exact experiment, examining scrupulously all the phenomena to be seen in the flight of birds. He began by measuring — by means of a long series of systematic measurements — the amount of the resistance of the air which the bird's wing has to overcome when in motion.

These experiments and measurements were for a long period made only by Otto Lilienthal, with the help of his brother. They showed the important and new result, that the curved wings, which nature, as we know, provides exclusively for her subjects, have a much more effective form than the flat surface hitherto so often constructed by men.

Besides this, Lilienthal was the first to point out the phenomenon which he thought was the probable explanation of the action of birds in sailing flight; that is, the existence of air-currents with upward tendency.

According to the observations made by Lilienthal these currents form on the average an angle of 3½ degrees with the line of the horizon.

Otto Lilienthal described the results of his numerous experiments in his pamphlet of the year 1889, entitled "The Flight of Birds as a Basis for the Art of Flying."

Shortly afterwards with the greatest zeal he again took up the practical attempts at flying which he had begun so long before. He had come to the conclusion that he could scarcely attain the solution of the problem of flight in his study, but that he must take the knowledge he had gained by observation and calculation out into the open air, to test with the wind, and in the element for which it was made, the apparatus constructed according to the theories he had developed. Theorizing alone would never bring about success. Brooding over and calculating about it would not bring one to the desired goal. One must draw

up plans, build a machine, and then experiment with it. Lilienthal was right in pointing to the example of the bicycle to show how important practical experiments are in contrast to pure theory. Without doubt, our ancestors would have shaken their heads incredulously over the problem of the bicycle; it was first solved practically and now has come the theoretical solution. Of all the various methods of flying which nature shows us, sailing flight seemed the most worthy of imitation. It allows, as observation shows, the swiftest and most uninterrupted motion forward with a minimum of physical exertion. The solving of the mystery of this sailing-flight must therefore be the most important task of the flight technician.

The apparatus used by the experimenter in resuming his attempts in the spring of 1891 had the shape of birds' wings when spread out. The cross-section through the wing lying in the plane of the direction of flight was curved parabolically; the surfaces of the wings comprised in the beginning 10 square metres; they decreased gradually on account of various changes and repairs to 8 square metres. [The width comprised at its greatest 7 m. by 2 m.] The framework of the wings was formed of willow-wood; the covering was made of sheeting covered with wax. The weight of the apparatus was about 18 kilos.

In order to hold the apparatus the arms are placed in two cushioned openings in the frame, the hands at the same time grasping two corresponding handles. In this way the wings are perfectly under control, and may be safely leaned on in the air.

At first, of course, the flying experiments were made only from a low height and when there was no wind. Lilienthal made a spring-board on a large lawn in his garden in Lichtefelde which could be made higher by degrees; when first experimenting the board was but one metre high, later it was raised to two metres. On the spring-board he could take a run of eight metres in length. In spite of the jump the landing on the soft earth was gentle, so that a jump like this could be repeated many times without resulting in the least weariness or danger.

On having practised sufficiently the jumping off in this manner without wind, he selected another practising ground between Werder and Gross-Kreutz where several mounds of larger size, standing alone, made the experiments possible. Here it was found at once that in these experiments particular attention must be given to the wind then blowing. It is necessary when floating to move against the wind, for if one falls away from the wind, the pressure of the wind is felt, and the experimenter is not able to resist the one-sided effect. A vertical steering surface therefore had to be put on, thus enabling the apparatus to go against the wind.

On the grounds between Werder and Gross-Kreutz the jumping was done very frequently from greater heights and with winds of different force; a great deal of new experience was thus obtained. The final result was, that jumps of 20–25 metres' length could be made from the highest jumping point there, from a height of 5 to 6 metres. This was done when there was no wind as well as with winds of different force.

The difference showed itself particularly in the duration of the flight; the stronger the winds, the longer the journey in the air. The fact that landing when there is no wind is often a rather violent affair corresponds to what has been said, and it is therefore necessary to raise the wings a little in front shortly before landing, in order to mitigate the harshness of the shock and to prevent tilting over. This, however, refers only to flight when there is no wind; if the flight is against the wind, the landing on the ground is of an absolutely gentle nature.

The practising places not offering enough space to cover longer distances from greater heights, another spot, suitable for continuing the experiments, had to be chosen in the following year, 1892.

Such a place was found between Steglitz and Südende. The slopes here have a height of about 10 metres.

The experiments were made with an enlarged apparatus with a surface of 16 square metres and 24 kilos' weight, at a velocity of the wind up to 7 metres. He could take a start up to the jumping place, thereby obtaining a relative velocity of the air

of 10 metres per second. Under these circumstances the first part of the sailing flight was almost horizontal; in its further course the line of flight sank considerably and declined rather suddenly at the end, as the wind loses a part of its force in the lower strata. In the most favorable case the length of the jump would be equal to 8 times the height of the jumping place above the landing point.

The surroundings of Berlin having a great dearth of good places for trying such flying experiments, Lilienthal constructed at Maihöhe near Steglitz a flying station of his own in the spring of 1893. A small declivity on this hill was arranged for a station for sailing flights. A tower-like shed was built, from the roof of which the flights were made, and which thus afforded a jumping place of 10 metres' height. The interior of the shed was used for storing the apparatus. The roof, which for the sake of a more secure start was covered with turf, sloped down, as did the declivity round the shed, towards south-west, west, and north-west. The apparatus showed a change as compared with that of previous years; it could be folded together, like the wings of the bat. It could, in consequence of this arrangement, be removed more easily and stored at almost any place.

It was only seldom, however, that the wind was favorable on the Maihöhe, and it was thus most important for the energetic continuing of the flying experiments that — in 1893 — Lilienthal succeeded in finding grounds which were suitable for his purposes in every respect. These are on the Rhinow mountains near Rathenow. Out of surrounding flat plough-lands there rises a chain of hills covered only with grass and heath, of up to 60 or even — as at the Gollenberg — up to 80 metres' height above the plain. The hills offer on every side descents, at an angle of from 10 to 20 degrees; and it is possible here to select a suitable position in whatever direction the winds make desirable, in order to glide above them through the air. The grounds really appear to be made for such flying experiments. The wind does not produce such gusts as at the flying tower at Steglitz, where one would always receive an irregular gust of wind from below, when passing the edge of the jumping

place. Often enough this gust threatened to be fatal. Besides, this uniform acclivity permitted landing anywhere.

The wings which were used showed some changes as compared with those used previously. Their weight is 20 kilos, the complete weight just 100 kilos, the width from tip to tip 7 metres, the greatest breadth 2½ metres, the complete surface 14 square metres, a size which appears to be fully sufficient.

The wings are lowered when the experimenter runs downhill against the wind; at the proper moment he raises the supporting surfaces a little, so that they are about horizontal; then while poising in the air he endeavors by suitably changing the point of gravity to give to the apparatus such a position that it shoots quickly forward while lowering itself as little as possible. After a short time a great progress in the safe management of the apparatus could be observed. Very often sailing flights of 200 to 300 metre length were made from a height of 30 metres; a great additional progress consisted in the fact that he succeeded in directing the course of flight to the right and left. Changing of the point of gravity is effected by stretching the legs in one or the other direction; even a slight change of the centre of gravity brings about at once a decline of the supporting surfaces towards the direction desired, the pressure of the air also increasing on this side. The direction of the course of flight then deviates to that side. Several times during the experiments the deviation from the straight line of flight was carried so far that Lilienthal would at times return to the starting place.

A place which was very well suited for his experiments, and much more conveniently situated, was procured by Lilienthal in the spring of 1894, in Gross-Lichterfelde near Berlin; he caused a conic hill to be thrown up, which, having a height of 15 metres and at the basis a diameter of 70 metres, should admit of flying experiments in whatever direction the wind blew.

On this place he tried with good success his new flying apparatus, consisting of two surfaces arranged one above the other.

He had come to the point already that the experiments regarding sailing flight could be considered as being completed, and he proposed to take up the second task, viz., the imitating of the rowing flight of birds. A light machine, weighing in all only 40 kilos and supplying 2½ horse-power for a short time (4 minutes), was constructed and tested several times. Lilienthal was therefore certainly justified in his words, when he declared in a lecture given in July, '96, in the Berlin trade exhibition buildings, that he had strong hopes of being able to further still more the development of the flying sport; but an accident put an untimely end to his endeavors on the 9th of August.

He had made, on that fatal day, a very extensive sailing flight on the Rhinow mountains, and thereby the special steering of the movable horizontal tail had proved to be very satisfactory; he then wanted to undertake a second flight of as long a duration as possible, and wanted to define the duration of the flight.

As a rule, such flights would last from 12 to 15 seconds. He gave the timing-piece to his assistant. According to the statement of the latter, the flight was — up to half of the course of flight — almost horizontal; then the apparatus had suddenly tilted over in front, and had shot down rapidly from a height of 15 metres, being completely tilted over on the ground. The daring sportsman was dragged from the *débris*. His spine being broken, he died twenty-four hours later. . . .

At present one cannot foresee what development may be in store for the principles laid down by Lilienthal in the art of flying: one thing however is certain, that not one of the numerous explorers and experimenters who have busied themselves with the problem of flying has done so much as Lilienthal to bring the difficult problem nearer its solution. It has therefore been justly emphasized, in the many accounts and debates which Lilienthal's experiments have called forth over the whole world, that he possessed three qualities in happiest union: He was first a thorough mathematician and physicist, and had given important contributions to the theory of flight by reason of his untiring observations and measurements of the resistance of the air to curved surfaces. Second, being a clever constructor,

and especially as mechanical engineer, he was able to build the apparatus himself as he thought best fitted for imitating the flight of birds. Third, he possessed great daring and physical dexterity, so that he was in himself fitted for making experiments in flying.

Therefore his memory will be faithfully cherished by all those who have decided to labor on in the field of work which he made his own.

[From Aero. Ann., 1896.]

OCTAVE CHANUTE.

(WITH PORTRAIT.)

Octave Chanute, ex-President of the American Society of Civil Engineers, was born in Paris, France, Feb. 18, 1832, and came to the United States in the latter part of 1838. He received his education chiefly in New York City, and began the practice of his profession as a civil engineer in 1849, on the construction of the Hudson River Railroad, under John B. Jervis, Chief Engineer.

He was gradually promoted as the work progressed over the several divisions of the road, and when he left the service of that company, in 1853, he was Division Engineer at Albany, in charge of the completion of terminal facilities and maintenance of way between Hudson and Albany.

In 1853 he went to Illinois with H. A. Gardner, previously Chief Engineer of the Hudson River Railroad, and was there engaged in building what is now a part of the Chicago & Alton Railroad, between Joliet and Bloomington, in Illinois. Mr. Chanute remained upon this work until 1854, when he was made Chief Engineer of the eastern portion of what is now the Toledo, Peoria, & Warsaw Railroad. He built this road from Peoria to the Indiana State line, a distance of about 112 miles, and remained in charge of maintenance of way until 1861. In the latter year he became Division Engineer, with similar duties, on the Pittsburg, Fort Wayne, & Chicago Railroad, between Chicago and Fort Wayne.

In 1862 he was for six months Chief Engineer of Maintenance of Way of the Western Division of the Ohio & Mississippi Railroad, from St. Louis to Vincennes. In 1863 he became Chief Engineer of Maintenance of Way and Construction of the re-

Plate VIII.

OCTAVE CHANUTE.

organized Chicago & Alton Railroad, and remained upon that line until 1867.

During this connection, having been invited to submit a design for the proposed Union Stock Yards of Chicago, his plan was selected in competition with a number of others and he built these yards as Chief Engineer. He was also awarded a premium for a competitive design for a bridge across the Missouri River at St. Charles, Missouri. In 1867 Mr. CHANUTE went to Kansas City, Mo., as Chief Engineer of the bridge across the Missouri River at that point. This was the pioneer bridge across the Missouri River, and as the river pilots and riparian dwellers had given this stream a bad reputation, the successful completion of this bridge across it in 1868 attracted great attention and interest.

Meanwhile the building of railroads had begun in Kansas, and while yet occupied in the completion of the bridge Mr. CHANUTE was placed in charge as Chief Engineer, first of the construction of the Kansas City, Fort Scott, & Gulf Railroad, from Kansas City to the north line of the Indian Territory, 160 miles; next of a parallel line in the same interest, then known as the Leavenworth, Lawrence, & Galveston Railroad, from Lawrence, Kansas, to the Indian Territory; next of a connecting line between the two, known as the Kansas City & Santa Fé Railroad, and lastly of the Atchison & Nebraska Railroad from Atchison northward.

While simultaneously in charge of the construction of these four railroads, he also designed and built the Union Stock Yards at Kansas City; and in 1871, as the work drew to a close, he became general Superintendent of the Leavenworth, Lawrence, & Galveston Railroad.

In 1873 he was offered and accepted the position of Chief Engineer of the Erie Railway, which, having changed its management, was planning to make extensive improvements. These were to consist of doubling the tracks and narrowing the gauge; building an extension to Chicago and another to Boston, involving the Poughkeepsie bridge since built in another

interest; building sundry branches, and improving the property generally at an estimated outlay of some fifty millions of dollars, which it was expected to obtain in England.

The panic of 1873 and the subsequent financial depression prevented the full carrying out of this programme. Mr. CHANUTE, however, remained upon the Erie Railway 10 years, during which time much of the line was double-tracked upon improved grades, the gauge reduced to the standard by laying down a third rail, and the facilities of the line largely improved. In 1875 he was made Assistant General Superintendent, and in 1876 was placed temporarily in charge of the motive power and rolling stock, in addition to his duties as Chief Engineer. This gave him an opportunity of readjusting the locomotives as well as the grades, so that the through freight train, which averaged 18 cars when he first became connected with the line, had grown to 35 cars when he closed his connection with the road in 1883, when he removed from New York to Kansas City, in order to look after his personal interests, and to open an office as Consulting Engineer.

In this latter capacity he took charge of the construction of the iron bridges during the building of the Chicago, Burlington, & Northern Railroad between Chicago and St. Paul in 1885, and of those of the extension of the Atchison, Topeka, & Santa Fé Railroad, from Kansas City to Chicago, in 1887 and 1888; the latter involving, besides a number of minor streams, the Missouri River bridge at Sibley, and the Mississippi River bridge at Fort Madison.

In 1889 Mr. CHANUTE removed his office to Chicago, where he is now principally engaged in promoting the preservation of timber against decay by chemical methods; he being of the opinion that the time has now fully arrived when large economies are to be attained in this country by employing the methods which are in current use abroad.

Mr. CHANUTE became a member of the American Society of Civil Engineers, Feb. 19, 1868, and has contributed a goodly number of papers to its Transactions. Among these may be

mentioned, "The Elements of Cost of Railroad Freight Traffic," "Rapid Transit and Terminal Freight Facilities," "The Preservation of Timber," the latter two being reports by committees of which he was chairman; "Engineering Progress in the United States," "Repairs of Masonry," and "Uniformity in Railroad Rolling Stock," besides some contributions to various other societies.

The foregoing biographical sketch is reprinted from *Engineering News*, N.Y., 1891. Since it appeared, Mr. Chanute has rendered to the cause of aeronautical science a service of the greatest value. He has written one of the most important books[1] on flying machines which has ever appeared; he took an active part in the proceedings of the International Conference on Aerial Navigation held in Chicago at the time of the World's Fair; he has also given most generous pecuniary aid to experimenters in need of money.

His high attainments as an engineer enable him to estimate with rare precision the value of the experiments made by others and to show investigators just what bearing their individual work has upon the world's work. — *Ed.*

[1910. Mr. Chanute still lives in Chicago and rejoices to have seen his anticipations realized.]

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[1] "Progress in Flying Machines," N.Y., 1894.

[From AERO. ANN., 1897.]

RECENT EXPERIMENTS IN GLIDING FLIGHT.

BY O. CHANUTE.

HAVING for a number of years studied the physical principles underlying flight, and having passed in review the experiments of others in a series of articles which eventually swelled into a book,[1] I ultimately reached the conclusion that the contingent compassing of artificial flight by man involved the study of at least ten separate problems, or the devising of means for observing and mastering the conditions enumerated as follows:

1. The resistance and supporting power of air.
2. The motor, its character and its energy.
3. The instrument for obtaining propulsion.
4. The form and kind of the apparatus.
5. The extent of the sustaining surfaces.
6. The material and texture of the apparatus.
7. The maintenance of the equilibrium.
8. The guidance in any desired direction.
9. The starting up under all conditions.
10. The alighting safely anywhere.

It is probable that some of these problems can be solved in more ways than one, and these solutions must then be harmoniously combined in a design which shall deal with the general problem as a whole, before the best possible result is attained.

I further reached the conclusion that the seventh problem, the maintenance of the equilibrium under all circumstances, was by far the most important, and the first which should be solved; that until automatic stability, at all angles of flight and conditions of wind, was evolved, and safety thereby secured, it

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[1] "Progress in the Flying Machines," M. N. Forney, N.Y., Editor, 1894.

would be premature to seek to apply a motor or a propelling instrument in a full-sized machine, as these additions would introduce complications which might be avoided at the beginning.

I seriously doubted, at first, whether automatic stability could be secured with an artificial machine; whether such combinations could be devised, for an inanimate apparatus, as to perform the complicated functions of the life and instinct of the birds, who probably preserve their balance through almost unconscious reflex action of their nerves and muscles. Observation, however, indicated that this might be automatic, requiring no thought under ordinary conditions, and the final conclusion was reached that it might be possible to evolve an artificial apparatus which should afford automatic stability and safety most of the time; that the variations of the wind were the great difficulties to be encountered, that they must be met and overcome, and that perhaps they might be utilized in obtaining propulsion and support, as is daily done by the soaring birds.

I therefore published an article in the "Engineering Magazine" for April, 1896, in which I advised those seeking a solution of the problem of flight to turn their attention to experiments in soaring flight, with full-sized apparatus carrying a man, as the quickest, cheapest, and surest way of ascertaining the exact conditions which must be met in practical flight.

This mode of procedure doubtless involves a certain amount of personal danger of accident. It might be pointed out that the advice is easy to give, but hazardous to follow, and so I further determined to try such experiments myself, so far as my limited personal means would allow.

For this purpose I secured the services of Mr. A. M. Herring, who had tried some experiments of his own. He rebuilt for me his Lilienthal apparatus, with which he had made some gliding flights in 1894, and he also built another full-sized gliding apparatus after a design of my own.

These were completed in June, 1896, and on the 22d of that month we, a party of four persons, went into camp in the desert

sand hills on the south shore of Lake Michigan, just north of the station of Miller, Ind., 30 miles east of Chicago.

These sand hills have been piled up by the wind blowing the sand from the beach. They gradually increase in altitude, from a point about 10 miles east of Chicago to the vicinity of St. Joseph, Mich., on the east shore of the lake, where they attain a height of 200 or 300 feet. They occupy a strip two to five miles wide around the south and south-eastern turns of Lake Michigan, and are bleak, bare, and deserted, being entirely incapable of cultivation. North of Miller, Ind., these hills rise about 70 feet above the lake. They are of soft yellow sand, almost bare of vegetation, and face in every direction of the compass, so that almost all directions of wind can be utilized in gliding experiments.

The method of carrying on these adventures is for the operator to place himself within and under the apparatus, which should, preferably, be light enough to be easily carried on the shoulders or by the hands, and to face the wind on a hillside. The operator should in no wise be attached to the machine. He may be suspended by his arms, or sit upon a seat, or stand on a dependent running board, but he must be able to disengage himself instantly from the machine should anything go wrong, and be able to come down upon his legs in landing.

Facing dead into the wind, and keeping the front edge of the supporting surfaces depressed, so that the wind shall blow upon their backs and press them downward, the operator first adjusts his apparatus and himself to the veering wind. He has to struggle to obtain a poise, and in a moment of relative steadiness he runs forward a few steps as fast as he may, and launches himself upon the breeze, by raising up the front edge of the sustaining surfaces, so as to receive the wind from beneath at a very small angle (2 to 4 degrees) of incidence. If the surfaces and wind be adequate, he finds himself thoroughly sustained, and then sails forward on a descending or undulating course, under the combined effects of gravity and of the opposing wind. By shifting either his body or his wings, or both, he can direct his descent, either sideways or up or down, within certain limits;

Fig. I. — GLIDING MACHINE.

Fig. 2.

he can cause the apparatus to sweep upward so as to clear an obstacle, and he is not infrequently lifted up several feet by a swelling of the wind. The course of the glide eventually brings the apparatus within a few feet of the ground (6 to 10 feet), when the operator, by throwing his weight backward, or his wings forward if they be movable, causes the front of the supporting surfaces to tilt up to a greater angle of incidence, thus increasing the wind resistance, slowing the forward motion, and enabling him, by a slight oscillation, to drop to the ground as gently as if he had fallen only one or two feet.

These manœuvres require considerable quickness and dexterity, yet they are easily learned in a few days, the principal rule to be learned being that the movements to be bodily made are the reverse of those instinctive motions which would occur to catch one's self from falling if walking on the ground. In point of fact, we found that a week's practice sufficed for a young, active man to become reasonably expert in these manœuvres, and hundreds of glides were made with the several machines, experimented in 1896 under variable conditions of wind, without the slightest personal accident.

As before stated, we went into camp on the 22d of June, 1896. The party consisted of Mr. A. M. Herring, already mentioned, Mr. W. Avery, an electrician and carpenter, Mr. William Paul Butusov, a former sailor, and myself. The tent was large enough to shelter the machines, but we learned in a few days that this precaution was unnecessary, and that they could be safely left exposed to the wind, outside, by tying them down to pegs or to bushes, or even by loading them down with sand. There was a fishing station of two houses within a mile of the tent, from which outside aid might have been obtained in the improbable case of an accident. Miller Station was two miles inland, and, having come through that station with our suspicious baggage, we soon had more visitors than was altogether pleasant in preliminary experiments.

The Lilienthal machine was first set up. It is shown, poised for a flight, in Plate IX., Fig. 1. The wings were 20 feet from tip to tip, 7 feet 6 inches in maximum breadth, and measured

168 square feet in surface, with a weight of 36 pounds. Mr. Herring, who had used it before, took the lead in gliding with it.

It was realized from the first that the machine was difficult to handle and to poise in the wind. The variable puffs pelted the apparatus; they occasionally lifted one wing more than the other, or rocked the machine fore and aft, so that a struggle was necessary before a poise could be obtained. Once under way the same action continued, and the operator was compelled to shift his weight constantly, like a tight-rope dancer without a pole, in order to bring the centre of gravity directly under the centre of pressure and to avoid being upset. This, in fact, is the principle of the Lilienthal apparatus. The equilibrium depends upon the constant readjustment of the weight, so as to coincide with the variable position of the centre of pressure due to the shifting direction and force of the wind. Lilienthal, who evolved this machine, so superior to any that had preceded it, was an expert in its use. He made thousands of flights without serious accident; but it is due to those who may desire to repeat such experiments to state here plainly that we found it cranky and uncertain in its action and requiring great practice. If strongly built it was not, however, nearly so hazardous to life and limb as the above statement would seem to imply. The radiating ribs forming the frame of the wings extend downward about as low as the waist of the operator when in flight, and whenever an awkward landing is made, by reason of the apparatus tilting to one side or the other, the ribs on that side are the first to strike the ground. Acting as springs, breaking or not as the case might be, they save the operator from bodily harm even in a descent of 20 feet. These breakages were easily repaired by wiring on wooden splints to the ribs, so that practice could be resumed in a few minutes.

About 100 glides were made with this machine, the longest being 116 feet, and the heights started from were 20 to 30 feet in winds of 12 to 17 miles per hour. Mr. Avery proved an apt pupil, and in the course of a week learned to manage the machine nearly as well as Mr. Herring. Mr. Butusov did not do so well and was upset, but not harmed. I did not venture

myself, feeling that I was no longer young and active enough to perform such acrobatic exercises without breaking the apparatus. After it had been broken, mended, tried again, and overhauled a goodly number of times, it was finally decided, on the 29th of June, to discard it, and it was accordingly broken up.

This decision was most unfortunately justified on the 10th of the succeeding August, when Herr Lilienthal met his death while experimenting with a machine based on the same principle, but with two superposed sets of wings. This deplorable accident removed the man who has hitherto done most to show that human flight is probably possible, who was the first in modern times to endeavor to imitate the soaring birds with full-sized apparatus, and who was so well equipped in every way that he probably would have accomplished final success if he had lived.

Having discarded the Lilienthal machine, we next turned our attention to the apparatus after my own design. This was based upon just the reverse of the principle involved in the Lilienthal apparatus.[1] Instead of the man moving about, to bring the centre of gravity under the centre of pressure, it was intended that the wings should move automatically so as to bring the movable centre of pressure back over the centre of gravity, which latter should remain fixed. That is to say, that the wings should move instead of the man.

The apparatus consisted in 12 wings, each 6 feet long by 3 feet wide, measuring $14\frac{3}{4}$ square feet in area, each pivoted at its root to a central frame, so that it could move fore and aft, this action being restrained by springs. The main frame was so constructed that the wings could be grouped in various ways, so as to ascertain the best arrangement for maximum support and for counterbalancing the effects of wind gusts, if possible. The total wing surface was 177 square feet, and the weight was 37 pounds. Fig. 2, Plate IX., shows the first grouping tested, which was found at once to be reasonably steady, but deficient in lifting power. It was recognized that the wings interfered

[1] To establish priority of invention a patent has been applied for.

with each other's efficiency; that the wind was deflected downward by the front wings, so that the middle and rear wings did not afford the same sustaining power as at the front. After making a few glides with this arrangement, a series of changes was tried to ascertain what was the best grouping and the best distance between the wings in order to obtain the maximum lift and the greatest steadiness. The paths of the wind currents in each arrangement of the wings were indicated by liberating bits of down in front of the machine, and, under their guidance, six permutations were made, each of which was found to produce an improvement in actual gliding flight over its predecessors.

The final arrangement to which this series of experiments led is shown on page 75. Five of the pairs of wings had gradually accumulated at the front, and the operator was directly under them, while the sixth pair of wings formed a tail at the rear, and being mounted so as to flex upward behind in flight, preserved the fore and aft balance. It was at once demonstrated that this apparatus was steady, safe, and manageable in winds up to 20 miles an hour. With it about 100 glides were made. The longest of these was 82 feet, in a descending course of about 1 in 4, against a wind of 13 miles an hour; the object constantly in view being not to make long glides, but to study the equilibrium of the machine and the principles which should govern in developing it further. These were found to be that the supporting surfaces should be concentrated at the front and the man placed directly under them; that the lowest wings should be at least 2½ feet above the ground; that they should be about two-thirds of their breadth apart vertically, and not less than their breadth apart horizontally, being set so as to present an angle of incidence of 3 to 7 degrees above the horizon when in flight, and that the wings should be pivoted so as to move very easily, the friction upon this first set of pivots having been found entirely too great to permit the wings adjusting themselves easily to the variations of the wind, and the man having had to move his body.

Having ascertained these facts, the experiments were termi-

Plate X.

CHANUTE'S 1896 GLIDING MACHINE IN FLIGHT.

nated on the 4th of July, and the equipment was sent back to Chicago in order to rebuild the machine.

It may safely be asserted that more was learned concerning the practical requirements of flight during the two weeks occupied by these experiments than I had gathered during many previous years of study of the principles involved, and of experiments with models. The latter are instructive, it is true, but they do not reveal all the causes for the vicissitudes which occur in the wind. They do not explain why models seldom pursue exactly the same course, why they swerve to the right or left, why they oscillate, or why they upset. When a man is riding on a machine, however, and his safety depends upon the observance of all the conditions, he keenly heeds what is happening to him, and he gets entirely new and more accurate conceptions of the character of the element which he is seeking to master.

The fact which most strongly impressed itself upon us was the inconstancy of the wind. It is incessantly changing in direction and in strength. This fact is not new, it has been well shown experimentally by Mr. A. F. Zahm, by Professor Langley, and probably by others, but its effects upon a man-ridden machine must be seen and felt to realize that this is the great obstacle to be overcome in compassing artificial flight. It cannot be avoided, it cannot be temporized with, and it must be coped with and conquered before we can hope to have a practical flying-machine.

One remarkable feature of the wind, however, struck us as hitherto unknown, or at least unmentioned. *The wind gusts seem to come in as rolling waves*, rotating at a higher speed than the general forward movement. The buffetings which the apparatus received from the wind, while the operator was endeavoring to steady it, preparatory to a flight, seemed to indicate that he was struggling with a rotary billow which produced the fluctuations. Professor Langley has termed these fluctuations "the internal work of the wind," and it is quite conceivable that they should be produced by a revolving motion, striking the surfaces with velocities varying with the distance from the

centre of rotation, and producing all the pulsations which have been revealed by the instrumental measurements.

Mr. Herring first called my attention to this feature of the wind, and I have ever since been wondering how I could, for so many years, have been watching smoke curling away from chimneys, steam convolving from trains, or dust and leaves whirling in wind gusts, without realizing that the elastic tenuity of air must perforce produce rotary motions much more active than those which occur in water.

This observation, if confirmed by further investigation, promises to give us a better understanding of the forces to be mastered. There are indications that there is a certain synchronism about these air waves, and that arrangements can be devised, not only to encounter them, but to avail of them in securing propulsion and automatic stability.

Be this as it may, we returned to Chicago much encouraged by the result of these preliminary experiments, with much clearer ideas as to the difficulties to be surmounted, and with good hopes that by reconstructing the machine we could obtain still better performances.

The original twelve-winged machine was reconstructed by pivoting the wings upon ball-bearings placed at the top and bottom of wooden uprights fastened to the main frame. The wings at the front were reduced to ten in number, in order to space them further apart without increasing their total height, but one pair was soon taken off, and the required supporting surface was restored by placing a concave aeroplane over the top of the wings. Two pairs of wings, superposed, were placed at the rear, but one pair was taken off after the first few trials, and the apparatus, provided with a rear keel or rudder, assumed the shape shown in Plate XI., Fig. 1. The total supporting surface at the front was then 143.5 square feet, the wings at the back measured 29.5 square feet, and the weight was 33½ pounds. The ball-bearings are at the level of the lower and of the third pair of wings from the bottom in the figure, and each set of moving wings, four in number, is connected rigidly by vertical wooden rods and diagonal wire ties so as to move

Fig. 1.—CHANUTE'S 1896 GLIDING MACHINE.

Fig. 2.—CHANUTE'S TWO-SURFACE GLIDING MACHINE.

together. Elastic rubber springs at front and rear connect them with the frame and restrain the movements produced by the fluctuations of the wind and relative speed. The detailed construction of the apparatus is shown on Plate XII. It had been originally intended to erect the machine with five pairs of superposed wings at the front, and they were in fact put on, but the first few trials in the wind showed that the height and leverage were too great for easy control, and the top pair was accordingly taken off.

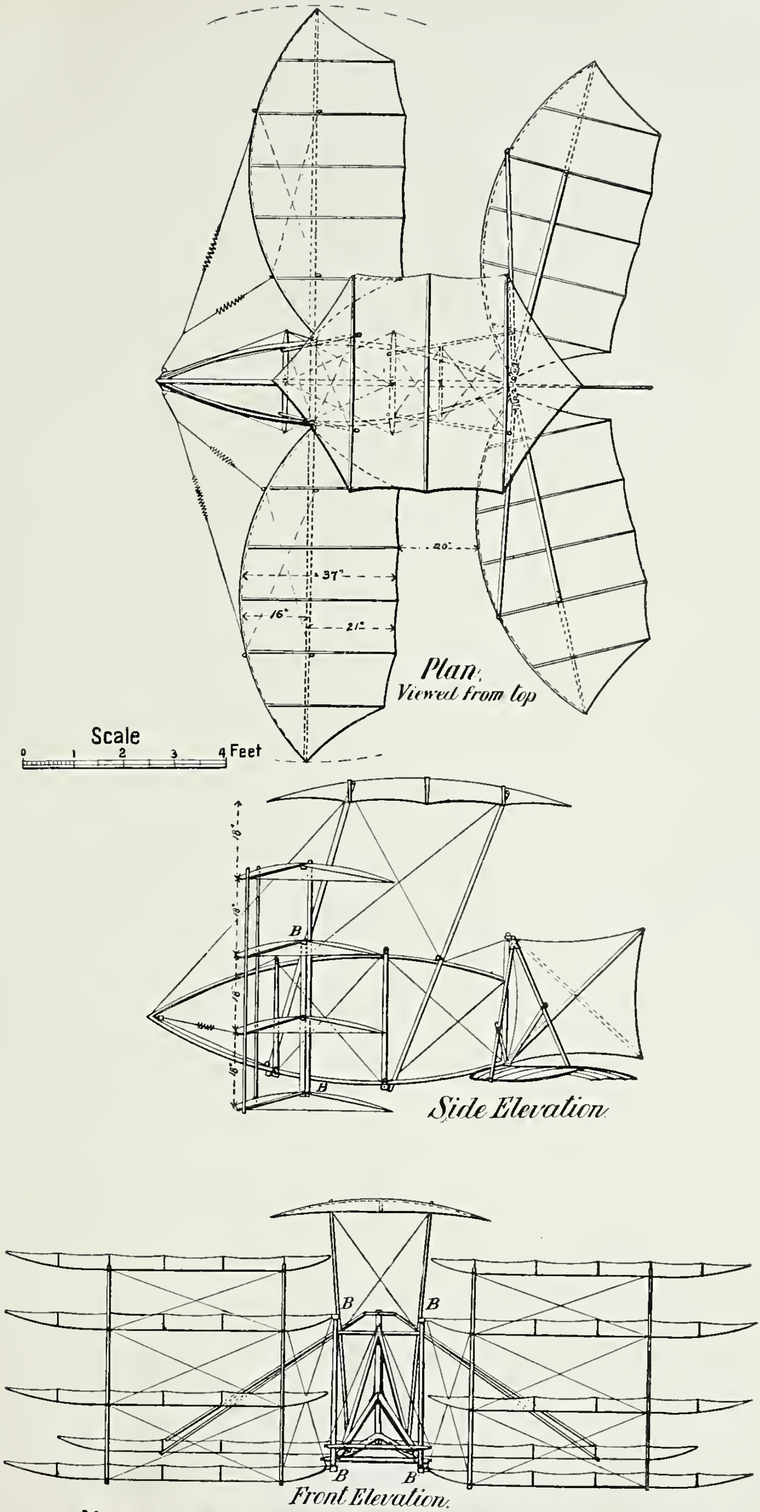
There was built simultaneously another full-sized machine, based upon a different principle. Instead of having pivoted wings, this consisted of three superposed concave surfaces, stretching 16 feet across the line of motion, by a breadth of 4 feet 3 inches, these surfaces measuring an aggregate of 191 square feet. The lower surface was cut away at the centre to admit the body of the operator. The machine was provided with a combined horizontal and vertical rudder, and its total weight was 31 pounds. The first few trials developed the fact that the sustaining power was in excess, and that the bottom surface was too near the ground. It was removed, leaving the apparatus in the condition shown on Plate XI., Fig. 2. The sustaining surfaces and the rudder were connected by an automatic device, designed by Mr. Herring, for the purpose of securing stability. The curvature of the wings (versed sine) was about one-tenth of the chord. Estimates were made in advance of head resistance due to the framing and to the drift of this machine. It was computed that it required a relative speed of 22 miles an hour and an angle of incidence of 3 degrees for support, and that its angle of gliding descent would be 10 degrees, or 1 in 5.6, which computations were fully verified in the experiments, as will be seen hereafter.

Still a third full-sized machine was constructed at my expense at the same time. This was designed by Mr. William Paul Butusov, who has already been mentioned as being present at the preliminary trials in June, and who stated that he had already tested with success a similar construction some seven years previously. This closely resembled the apparatus experimented

by Le Bris in 1855 and 1867. It consisted in a boat-like frame of ribs and stanchions, which might be covered with stout oil-cloth and thus transformed into a boat. Above this were four longitudinal keels of balloon cloth, stretched on a frame, each 8 feet long and 3 feet deep. The central space was left open, but the two side spaces were roofed over. This occupied 8 feet in width, and immediately above were placed the wings, each 16 feet long, by a maximum width of 7 feet, tapering to the tips. The total spread was, therefore, 40 feet from tip to tip, and above this again a square aeroplane or kite was placed, hung on trunnions at its centre, so that its angle of incidence might be varied at will by lines carried to the hands of the operator. The latter stood upright in the boat on a running board 8 feet long, and might therefore shift his weight to that extent by walking forward or backward, and he might also shift it about 3 feet sideways by leaning to one side or the other. The whole arrangement is shown in Plate XIII., Fig. 1, except the rudder and tail, which are partly hidden by the man, and which are moved by light lines passing over pulleys and carried to his hands. In addition to this a pair of parallel bars (curtain-poles) were fastened to the frame, to which the man might cling or brace himself.

When finally completed the apparatus spread 266 square feet of sustaining surface and weighed 160 pounds. The various parts (wings, keel-roofs, top aeroplane, and tail) were then tested by suspending them inverted, and loading them with sand to the maximum load they might be called upon to carry, and as some of them showed signs of crippling, or did cripple, they were strengthened with additional material until they were safe to stand the strains. This brought the total weight up to 190 pounds.

These three machines being ready, we again went to the sand hills on the 20th of August, 1896. Having on the previous occasion found the vicinity of Miller too accessible to the public, we went, this time, five miles further down the beach, where the hills were higher, the solitude greater, and the path more obscure to the railroad, which it reached at a sand-pit



MULTIPLE-WING GLIDING MACHINE, Invented by O. CHANUTE, C.E.

station consisting of a single house, and called Dune Park. The distance from our camp was about two miles, through a series of swamps, woods, and hills, so that intending visitors not infrequently got lost.

We went from Chicago by a sailing vessel in order to avoid arousing gossip at the railroad station, and in the afternoon of August 21st we got the material unloaded and the tent pitched at the experimental hill. We hoped to begin setting up the machines on the morrow.

Unfortunately, that very night a fearful storm and whirling wind came up from the south-west at 3 A.M. It blew the tent to ribbons, blew away and wrecked such wings as were not boxed, while all of the party and the provisions were drenched, the camp equipage being moreover scattered and damaged.[1] It became necessary to send at once to Chicago for another tent, which arrived at Dune Park by express in the afternoon of the twenty-second, but this disclosed our presence to the people at the sand pit, and some ten days later brought down the newspaper reporters to see what we were about.

Our party consisted of five persons, Mr. Herring, Mr. Avery, Mr. Butusov, already mentioned, Dr. Ricketts, — a young surgeon who found that function such an entire sinecure that he could only exhibit to us his talents in cooking,— and myself. In addition to this there was, for a time, a carpenter to erect the trestle work from which to launch the Butusov machine. The hill selected faced the north and rose 100 feet above the lake, there being an intervening beach of about 350 feet between its base and the water. It was of soft yellow sand with many bare slopes, but with occasional clumps of trees and bushes. To the south it sloped to a bare wilderness of sand.

The first machine which was repaired and set up after the tornado was the aerocurve, with three superposed fixed surfaces and automatic tail attachment. It was first tested on the 29th of August, with tentative glides from a height of 15 to 20 feet above the bottom of the hill, but it was found to rock so that the lower surface struck the ground, hard to manage, and to lift

[1] The frying-pan was blown 200 yards away.

more than required. The lower aerocurve was therefore taken off, thus reducing the sustaining surface to 135 square feet, and the weight to 23 pounds. This was thereafter found ample to sustain an aggregate weight of 178 pounds (23 pounds of machine and 155 pounds of operator), and all the subsequent experiments were made with this arrangement. During the next 14 days scores and scores of glides were made with this machine, whenever the wind served. It was found steady, easy to handle before starting, and under good control when under way, — a motion of the operator's body of not over 2 inches proving as effective as a motion of 5 or more inches in the Lilienthal machine. It was experimented in all sorts of winds, from 10 to 31 miles an hour, the latter being believed to be a higher wind than any gliding machine had been tried in theretofore, and yet the equilibrium was not compromised, the machine gliding steadily at speeds of about 17 miles per hour with reference to the ground, and of about 20 to 40 miles an hour with reference to the air, or relative wind. On one occasion a relative speed of 52 miles an hour was acquired in a descent. Some of the best glides made were as follows:

Operator.	Length in feet.	Time in seconds.	Angle of descent.	Height fallen, feet.	Speed, feet per second.	Descent of
Avery..........	199	8.	10°	34.6	24.9	1 in 5.75
Herring........	234	8.7	7½°	30.4	26.9	1 " 7.69
Avery..........	253	....	10½°	46.	....	1 " 5.50
Herring........	239	....	11°	46.3	....	1 " 5.24
"	220	9.	....	....	24.4	
"	235	10.3	....	....	22.8	
Avery..........	256	10.2	8°	25.5	25.1	1 in 7.18
Herring........	359	14.	10°	62.1	25.6	1 " 5.75

One of these flights is shown by Fig. 2, Plate XIII.

The varying flatness of the angle of descent was undoubtedly due to the varying strength of the wind, and also to its ascend-

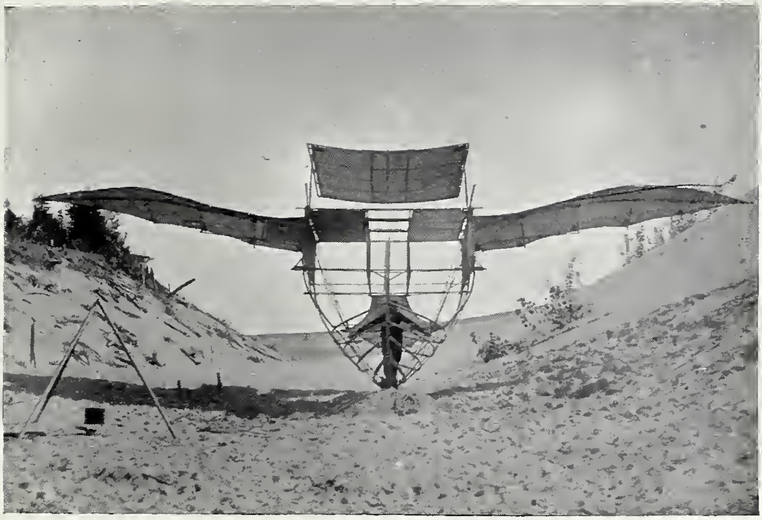


Fig. I.

Fig. 2.— A GOOD START.

ing trends as it struck the slope of the hill. The latter were exhibited by liberating bits of down at the foot of the hill, whence they would ascend parallel with the surface and pass over the top to the plain beyond. On many occasions the machine and man were raised higher than the starting point by increasing wind velocity, but this action was found to be much too irregular to be availed of as a source of power.

It was found that by moving the operator's body backward or forward, an undulatory course could be imparted to the apparatus. It could be made to rise several feet to clear an obstacle, or the flight might be prolonged, when approaching the ground, by causing the machine to rise somewhat steeply and then continuing the glide at a flatter angle. It was very interesting to see the aviator on the hillside adjust his machine and himself to the veering wind, then, when poised, take a few running steps forward, sometimes but one step, and raising slightly the front of his apparatus, sail off at once horizontally against the wind; to see him pass with steady motion and ample support 40 or 50 feet above the observer, and then, having struck the zone of comparative calm produced by eddies from the hill, gradually descend to land on the beach several hundred feet away.

A few hidden defects were gradually evolved, such as lack of adjustment in the automatic device, and occasional swerving out of the course in sudden gusts of wind; but safe landings were made in every case, by simply throwing the body back and causing the front edge of the aerocurve to rise so as to diminish the speed; and the machine was not once broken. It was kept out of doors moored to pegs driven in the sand, and was injured by storms on but three occasions. It was concluded, however; that a permanent machine of this kind should be arranged to fold up (as this was not) so as to admit of carrying it about and of sheltering it from the weather.

The movable winged machine (12 wings) was not set up till the 4th of September, 1896. Upon being tested, it was found at once that a mistake had been made in not providing entirely new wings for it. The old wings were so racked, twisted, and

distorted by their prior service that they did not lift alike, and that it was difficult to poise the machine and to balance it in the wind. Nothing is so important in such experiments as to keep the sustaining surfaces in perfect shape and to prevent any racking when under strains. This is inculcated to us by the birds, who are constantly "pluming" themselves when on the perch. They pass each flying feather through their beaks, repair those barbs which have become separated, rearrange the lap of the feathers, and beat their wings up and down to limber up the muscles. I have reason to believe that it was in consequence of the failure to keep his apparatus in constant rigid good order that Herr Lilienthal so unhappily lost his life. A correspondent in Germany, who had witnessed his exercises two weeks before the fatal fall, wrote me that he had found that in the particular machine with which the accident occurred "the connections of the wings and of the steering arrangements were very bad and unreliable," that he had remonstrated with Herr Lilienthal very seriously, and the latter had promised that he would put the apparatus in order, but, with that contempt of danger which long familiarity and thousands of successful flights is sure to create, it is much to be feared that he did not attend to it immediately, especially as he was about to discard that particular machine for a new one from which he expected great results.

It was also found that in spacing the wings of the twelve-winged machine further apart, it had been made too high. The top was 10 feet 6 inches above the ground, and the leverage of the wind made it difficult for the operator to control the machine. The top pair of wings was accordingly taken off, and the experiments thereafter made with the apparatus as cut down. In this shape it proved steady and manageable, the flights being over twice as long, with the same fall as with the original machine in June. The following are some of the glides made on the 11th of September against a wind of 22.3 miles per hour:

Operator.	Length in feet.	Time in seconds.	Speed, feet per second.	Remarks.
Herring	148	7.	21.1	Angle not measured.
Avery	174	7.6	22.9	" " "
Herring	166	7.5	22.1	" " "
Avery	183	7.9	23.1	" " "
Herring	172	7.8	22.	" " "

The angles were approximately 10 or 11 degrees, or 1 in 5.

This machine had been provided with a swinging seat, consisting of network with a narrow board at its front, and with a pair of swinging bars and stirrups against which the legs could be braced, so as to move the wings fore and aft by means of light lines running through pulleys. The heights started from being only 30 to 35 feet above the base of the hill, and the glides being accordingly very brief, these attachments could not be brought into action, but their efficacy was tested by suspending the apparatus between two trees and facing the wind with a man in the seat. It was found, as was expected, that by thrusting the wings forward the machine was tossed up, and *vice versa* that by thrusting one wing forward the machine turned towards the opposite side, and that these would be effective ways of directing the apparatus when under flight, either up or down, or in a circling sweep. The automatic regulation, however, did not work as well as was hoped, perhaps in consequence of inaccurate adjustment of the springs. The man still had to move about one inch to preserve the equilibrium when under way. The machine made steady flights and easy landings, and was not once broken in action. It is certainly considered safer and more manageable than the Lilienthal apparatus which we tested. No photographs were taken of this machine in flight, as it was not tested nearly so often as would have been desirable, and whenever it was, something always interfered to prevent getting the camera.

It must be confessed that the results with this apparatus were rather disappointing, and yet the principle is believed to be sound. As the variations of the wind are constantly changing the position of the centre of pressure, it is necessary that either the wings or the weight shall move, or that the angle of incidence relative to the air shall be absolutely maintained in order to keep the centre of pressure and the centre of gravity upon the same vertical line. These are the two principles which are involved in the two machines which have herein been described. Which of the two shall hereafter prove to be most effective in practical use, or whether the two can be combined, cannot be determined at present, but it is my judgment that one or two more seasons should be devoted to perfecting the automatic equilibrium, to eliminating hidden defects, and to adjusting the strength of the springs and moving parts, before it will be prudent to apply a motor, or to try to imitate the soaring of the sailing birds.

Towards the last we gathered such confidence in the safety of the machines that we allowed anybody to try them who wanted to. A number of amateurs took short flights, awkwardly of course, but safely. One of them was raised about 40 feet vertically and came down again so gently that he felt no jar upon alighting. Others glided from 70 to 150 feet, and all agreed that the sensation of coasting on the air was delightful, although they were somewhat timid about tempting fate too many times. Any young, active man can become expert in a week with either of these machines.

We performed nothing like continuous soaring with any of the machines. The fluctuations of the wind were entirely too irregular to be availed of; for a wind gust, which tossed a machine up, was almost immediately succeeded by a lull which let it down again. If we had had a long, straight ridge, bare of trees at its summit, and a suitable wind blowing at right angles thereto, we would have attempted to have sailed horizontally along the top of the ridge, transversely to the resulting ascending current. This manœuvre is frequently and easily performed by the soaring birds over the edge of a belt of trees. They

ride across the face of the ascending aerial billow, decomposing its upward trend into propulsion as well as support. The feat should be performable by man, and should, in my judgment, be attempted before circling flight is tried. It requires, of course, that the equilibrium shall be first mastered, and also that the angle of flight shall be flatter than with our machines. This was, as has been seen, from 8 degrees to 11 degrees, or a descent of 1 in 7 or 1 in 5. Now, the soaring birds generally sail at angles of 4 degrees to 6 degrees, or a descent of 1 in 15 to 1 in 9, and hence they lose very much less elevation. This disadvantage in the machines resulted from the increased head resistance due to the framing and spars as compared with the wing edges of the birds, and especially from the fact that in order to give the man easy command over his movements and to let him land on his feet, he has to be in the natural erect position. This produces a body resistance due to about 5 square feet of surface, while it would be that due to only about 1 square foot if the man were placed horizontally, as is the body of the bird. It is probable, however, that the machines can be improved in this respect, and that flatter angles of flight will be obtained than those recorded herein.

The apparatus of Mr. Butusov, like that of Le Bris, had been inspired by watching the sailing of the albatross in southern latitudes. He stated that having begun by experimenting with the main wings, he had been led to add various adjuncts, such as the keels and the top aeroplane in order to improve the stability. It was no part of the original programme to test such a machine, but in view of the degree of success said to have been attained both by Le Bris and by Mr. Butusov, it was determined to give the apparatus a trial.

As it weighed 190 pounds, and the operator's own weight was 130 pounds, a total of 320 pounds, it was necessary to furnish special appliances for launching the machine. This was provided for by building an inclined trestle work, which consisted in a pair of tallowed guides or ways, 8 feet apart, descending at an angle of 23 degrees down the slope of the sand hill selected, the top being 94 feet and the bottom 67 feet above

the lake. The last 10 feet of these launching ways was horizontal, and connected with the sloping portion by a curve of 5 feet radius. The ways stood about 11 feet above the side of the hill, the central space between them being entirely unobstructed, the supports being braced by raking posts and braces. The trestle faced due north, so as to avail of the north wind, which, blowing down the whole length of Lake Michigan, arrived with fewer of the whirls and eddies than prevailed with the winds coming from the south, south-east, or south-west. These had been disturbed by blowing over the sand hills, and it is a peculiarity well worthy of note by other experimenters that they will find it much preferable to avail of winds which have traversed across a sheet of water or a level plain than of those which have come over hills, trees, or other obstacles.

This fixed position of the launching ways, however, unfortunately required the waiting for a north wind to blow before experiments could be conducted with this apparatus. The prevailing winds in September were from the south, and there were many storms, so that the instances were rare indeed, during the three weeks which elapsed after the trestle and apparatus were completed, when the wind came from the right direction, and with just the velocity (18 to 25 miles per hour) which was desired. Hence the machine was not given that complete and thorough test which it would have received had the inventor accepted my proposal to launch from ways rigged up on a floating barge, which might have been anchored or towed against any wind of suitable velocity.

Before proceeding with the tests, the whole apparatus was carefully measured. It was ascertained that the whole sectional area of the framing, spars, wing edges, ribs, stanchions, guys, cords, etc., including 5 square feet for the body of the operator, was 44.92 square feet, reduced, however, by reason of the rounding of the parts to an equivalent of 33.28 square feet, which area, multiplied by the pressure, would give the head resistance; that the apparatus would require a relative speed of 25 miles an hour (3.06 pounds per square foot pressure) in order to float it at an angle of incidence of +2 degrees, and

that, therefore, if Lilienthal's coefficients were used, the total resistances would be:

Head resistance, 33.28 sq. ft. × 3.06 lbs.	= 101.83 lbs.
Tangential component, 266 sq. ft. × 3.06 lbs. × 0.008	= 6.51 "
Retarding component, 320 lbs. × (sin 2° = 0.035)	= 11.20 "
Total,	119.54 "

So that the angle of descent might be expected to be:

$$\frac{320 \text{ lbs.}}{120 \text{ lbs.}} = 1 \text{ in } 2.67 \text{ or } 22 \text{ degrees.}$$

These calculations were closely verified, as in the case of the other two machines.

It was the 15th of September (1896) before a proper wind served. It then set in from the north about noon and blew 28 miles an hour. The apparatus was accordingly placed in the ways, tested as to fit by running it up and down restrained by head and tail ropes, and then it was placed upon the level portion of the ways facing the wind. Additional guy lines were fastened to the wings, and Mr. Butusov got into the machine. The guy lines were manned, and the apparatus was suffered to rise 2½ to 3 feet above the ways, in order to test its balancing and the degree of control of the operator over its movements.

This appeared to be complete. A very slight step to the front or rear sufficed to depress or to raise the head of the machine, and the side motions were equally sensitive. The support was found to be ample from a 28-mile wind, and it was apparent that the great range of motion provided for the operator would give him command of the machine at all angles of incidence. The apparatus was then hauled down by the guy lines and settled back upon the ways squarely, resting thereon by means of four sliding shoes projecting from the machine on a line with the top of the boat-like body. It is shown in that position by Fig. 1, Plate IX.

It was desired next to launch it in ballast, and also to test it as a kite, and preparations were begun for that purpose; but a

small rip having been discovered in one of the wing coverings, and a buckling in one of the braces, it was thought more prudent to repair these before proceeding further, and the machine was removed from the ways.

The wind changed to the south-west in the night, but on the 17th it again blew from the north, with a speed, however, of but 12 miles per hour. In the hope of its freshening, the machine was got into the ways, loaded with 130 pounds of sand in bags, and rigged as a kite, by fastening a bridle to the keel of the boat and leading therefrom a long rope passing through a pulley fastened to a post in the sand, 250 feet away on the beach. This rope was handled by four men, with instructions to run with it so as to take up the slack as soon as the apparatus left the ways. Four guy lines, hanging down from the front and rear, and from each wing of the machine, were likewise manned, in order to control the movements of the kite in case of need.

All being ready, the restraining line was cut and the machine slid down the tallowed ways and took the air fair and level. It went horizontally some 20 feet, but its motion was then checked by the friction on the sand of the kite line, which the crew, gazing open-mouthed at the sight, failed to haul in as the machine flew forward. This check was sufficient to overcome the initial velocity proper to the machine, and the wind (12 miles an hour) was insufficient to sustain it. The apparatus glided downward and landed squarely on its keel about 100 feet from the end of the ways, a descent of about 1 in 2. The tip of one wing struck the hillside, but no harm was done as it flexed. Some three or four of the stanchions of the boat frame were, however, broken. These were replaced in two hours, but the wind had fallen so light by that time that the experiment could not be repeated.

To test the apparatus properly a north wind of about 25 miles per hour was required. This did not set in again till just before the advancing season compelled the breaking up of camp and returning to the city. On the 19th of September the equinoctial storm set in and blew from the north-west 56 to 60 miles an hour. Another gale of 60 miles an hour blew on the 22d, ac-

companied by heavy rains. These were followed by southerly winds, so that it was the 26th before the machine could be tested again. A wind then set in from the north-east, with a speed of 18 miles an hour, and although this was quartering, instead of dead ahead as was desired, it was determined to launch the apparatus. This was first attempted with the operator in the machine, but as the quartering wind greatly increased the friction of the launching ways and diminished the required initial speed, the operator was replaced by 90 pounds of sand in bags, and a rope was fastened to the front of the machine in order to increase its velocity by pulling thereon. The apparatus went off, but as soon as it had fairly left the end of the ways, the quartering wind swerved the head of the machine around, and it took a descending north-westerly course, describing a curved path. The tip of the left wing then struck the top of a tree, swinging the machine around further, and then this same wing struck the hillside and was broken. The machine then fell to the ground, landing upon its keel about 75 feet from the end of the ways, and a number of ribs and stanchions were broken, so that the repairs, if made, would probably have occupied a day or two.

It was evident that the machine was moderately stable; that on neither this nor on the previous trial would the operator have been hurt if he had been in the machine; but it was also evident that the apparatus, as then proportioned, glided at too steep an angle to perform soaring flight; that it would lose so much altitude when going with the wind that the loss would not be recuperated when turned to face the wind. It was recognized that this, as well as the other two machines, could be modified so as to materially reduce the head resistance and thereby flatten the angle of descent, but the season was so far advanced, the weather so inclement, that it was decided to break up camp and to return to the city. This was done on the 27th of September.

Such were the experiments. They occupied an aggregate of seven or eight weeks in the field, they were carried on without the slightest accident to the operators, and they made mani-

fest several important conclusions. The first is that it is reasonably safe to experiment with full-sized machines, if the methods and writings of Lilienthal be previously studied. The second is that experiments with full-sized machines, carrying a man, are likely to be more instructive and fruitful of eventual progress than experiments with models. The third is the inference that it is probably possible to evolve an apparatus with automatic stability in the wind, but that in order to do so, there must be some moving parts, apart from the man, in order to restore the balance as often as it is compromised. The fourth conclusion is that the problem of automatic stability will be most easily worked out with a light apparatus, so light as to enable the operator to carry it with ease, and so arranged as to enable him to use his legs in landing. The fifth conclusion is that it will require a good deal of experimenting to adjust the working parts, to regulate the springs, and to discover hidden defects, before it will be quite safe to try to perform soaring feats in the wind. The sixth is that the incessant fluctuations of the wind, which so very greatly complicate the problem of maintaining automatic stability, probably result from the rotary action of its billows, and future experimenters are urgently advised to study this action and to endeavor to meet it.

A word or two of caution may also be given. It is best to begin experimenting with a new machine in short and low gliding flights over bare and soft sand hills, but more ambitious flights and soaring feats should be attempted first over a sheet of water to mitigate the fall should anything go wrong. Experiments should not be tried in high or gusty winds, and the apparatus should be frequently examined and kept in constantly perfect order. Wire stays should be employed as sparingly as possible. Not only do they vibrate when the machine is under way, and so increase the resistance, but they get loose and allow the apparatus to become distorted. It is well to fly a model of a projected apparatus as a kite, but it does not follow that a satisfactory kite will make a good flying-machine, because the required angles of incidence are so different. A good kite will fly steadily at an angle of 20 or 30 degrees with the wind, but

Plate XIV.

CAMP CHANUTE, 1896, SOUTHERN SHORE OF LAKE MICHIGAN.

BLUE HILL METEOROLOGICAL OBSERVATORY.

From the Northwest, showing New Construction. See p. 208.

a good flying-machine needs to fly at an angle of 2 to 5 degrees to reduce the drift to the lowest possible.

I do not know how much further I shall carry on these experiments. They were made wholly at my own expense, in the hope of gaining scientific knowledge and without the expectation of pecuniary profit. I believe the latter to be still afar off, for it seems unlikely that a commercial machine will be perfected very soon. It will, in my judgment, be worked out by a process of evolution: one experimenter finding his way a certain distance into the labyrinth, the next penetrating further, and so on, until the very centre is reached and success is won. In the hope, therefore, of making the way easier to others, I have set down the relation of these experiments, perhaps at tedious length, so that other searchers may carry the work of exploration further.

One of Mr. Chanute's Gliders.

SOARING FLIGHT.

By Octave Chanute.

(*Reprinted from American* Aeronautics,[1] *April, 1909.*)

Note.—This paper, written for the International Aeronautical Congress of 1907 and revised in 1909, is here substituted for the articles by the same author which appeared in The Aeronautical Annuals of 1896 and 1897 referred to in the text.

THERE is a wonderful performance daily exhibited in southern climes and occasionally seen in northerly latitudes in summer, which has never been thoroughly explained. It is the soaring or sailing flight of certain varieties of large birds which transport themselves on rigid unflapping wings in any desired direction; which, in winds of 6 to 20 miles per hour, circle, rise, advance, return and remain aloft for hours without a beat of wing, save for getting under way or convenience in various maneuvers. They appear to obtain from the wind alone all the necessary energy, even to advancing dead against that wind. This feat is so much opposed to our general ideas of physics that those who have not seen it sometimes deny its actuality, and those who have only occasionally witnessed it subsequently doubt the evidence of their own eyes. Others, who have seen the exceptional performances, speculate on various explanations, but the majority give it up as a sort of "negative gravity."

The writer of this paper published in the "Aeronautical Annual"[2] for 1896 and 1897 an article upon the sailing flight of birds, in which he gave a list of the authors who had described such flight or had advanced theories for its explanation, and he passed these in review. He also described his own observations and submitted some computations to account for the observed facts. These computations were correct as far as they went, but they were scanty. It was, for instance, shown convincingly by analysis that a gull weighing 2.188 pounds, with a total supporting surface of 2.015 square feet, a maximum body cross-section of 0.126 square feet and a maximum cross-section of wing edges of 0.098 square feet, patrolling on rigid wings (soaring) on the weather side of a steamer and maintain-

[1] Aeronautics, published monthly at 1777 Broadway, New York. Seventh volume begins with issue of July, 1910. $3.00 per annum, U.S., $3.50 foreign. Specimen copies 25 cents.

[2] The "Aeronautical Annuals" of 1895, 1896, and 1897 may be found in the public libraries of every city in the United States having a population of 100,000 or more.—Ed.

ing an upward angle or attitude of 5 degrees to 7 degrees above the horizon, in a wind blowing 12.78 miles an hour, which was deflected upward 10 degrees to 20 degrees by the side of the steamer (these all being carefully observed facts), was perfectly sustained at its own "relative speed" of 17.88 miles per hour and extracted from the upward trend of the wind sufficient energy to overcome all the resistances, this energy amounting to 6.44 foot-pounds per second. It was shown that the same bird in flapping flight in calm air, with an attitude or incidence of 3 degrees to 5 degrees above the horizon and a speed of 20.4 miles an hour was well sustained and expended 5.88 foot-pounds per second, this being at the rate of 204 pounds sustained per horse power. It was stated also that a gull in its observed maneuvers, rising up from a pile head on unflapping wings, then plunging forward against the wind and subsequently rising higher than his starting point, must either time his ascents and descents exactly with the variations in wind velocities, or must meet a wind billow rotating on a horizontal axis and come to a poise on its crest, thus availing of an ascending trend.

But the observations failed to demonstrate that the variations of the wind gusts and the movements of the bird were absolutely synchronous, and it was conjectured that the peculiar shape of the soaring wing of certain birds, as differentiated from the flapping wing, might, when experimented upon, hereafter account for the performance.

These computations, however satisfactory they were for the speed of winds observed, failed to account for the observed spiral soaring of buzzards in very light winds and the writer was compelled to confess: "Now, this spiral soaring in steady breezes of 5 to 10 miles per hour which are apparently horizontal, and through which the bird maintains an average speed of about 20 miles an hour, is the mystery to be explained. It is not accounted for, quantitatively, by any of the theories which have been advanced, and it is the one performance which has led some observers to claim that it was done through 'aspiration,' *i.e.*, that a bird acted upon by a current actually drew forward into that current against its exact direction of motion."

A still greater mystery was propounded by the few observers who asserted that they had seen buzzards soaring in a dead calm, maintaining their elevation and their speed. Among these observers was Mr. E. C. Huffaker, at one time assistant experimenter for Professor Langley. The writer believed and

said then that he must in some way have been mistaken, yet, to satisfy himself, he paid several visits to Mr. Huffaker in Eastern Tennessee and took along his anemometer. He saw quite a number of buzzards sailing at a height of 75 to 100 feet in breezes measuring 5 or 6 miles an hour at the surface of the ground, and once he saw one buzzard soaring apparently in a dead calm.

The writer was fairly baffled. The bird was not simply gliding, utilizing gravity or acquired momentum, he was actually circling horizontally in defiance of physics and mathematics. It took two years and a whole series of further observations to bring those two sciences into accord with the facts.

Curiously enough the key to the performance of circling in a light wind or a dead calm was not found through the usual way of gathering human knowledge, *i.e.*, through observations and experiment. These had failed because I did not know what to look for. The mystery was, in fact, solved by an eclectic process of conjecture and computation, but once these computations indicated what observations should be made, the results gave at once the reasons for the circling of the birds, for their then observed attitude and for the necessity of an independent initial sustaining speed before soaring began. Both Mr. Huffaker and myself verified the data many times and I made the computations.

These observations disclosed several facts:

1st. That winds blowing 5 to 17 miles per hour frequently had rising trends of 10 degrees to 15 degrees, and that upon occasions when there seemed to be absolutely no wind, there was often nevertheless a local rising of the air estimated at a rate of 4 to 8 miles or more per hour. This was ascertained by watching thistledown and rising fogs alongside of trees or hills of known height. Every one will readily realize that when walking at the rate of 4 to 8 miles an hour in a dead calm the "relative wind" is quite inappreciable to the senses and that such a rising air would not be noticed.

2d. That the buzzard, sailing in an apparently dead horizontal calm, progressed at speeds of 15 to 18 miles per hour, as measured by his shadow on the ground. It was thought that the air was then possibly rising 8.8 feet per second, or 6 miles per hour.

3d. That when soaring in very light winds the angle of incidence of the buzzards was negative to the horizon—*i.e.*, that when seen coming toward the eye, the afternoon light shone on

the back instead of on the breast, as would have been the case had the angle been inclined above the horizon.

4th. That the sailing performance only occurred after the bird had acquired an initial velocity of at least 15 or 18 miles per hour, either by industrious flapping or by descending from a perch.

5th. That the whole resistance of a stuffed buzzard, at a negative angle of 3 degrees in a current of air of 15.52 miles per hour, was 0.27 pounds. This test was kindly made for the writer by Prof. A. F. Zahm in the "wind tunnel" of the Catholic University at Washington, D.C., who, moreover, stated that the resistance of a live bird might be less, as the dried plumage could not be made to lie smooth.

This particular buzzard weighed in life 4.25 pounds, the area of his wings and body was 4.57 square feet, the maximum cross-section of his body was 0.110 square feet, and that of his wing edges when fully extended was 0.244 square feet.

With these data, it became surprisingly easy to compute the performance with the coefficients of Lilienthal for various angles of incidence and to demonstrate how this buzzard could soar horizontally in a dead horizontal calm, provided that it was not a vertical calm and that the air was rising at the rate of 4 or 6 miles per hour, the lowest observed, and quite inappreciable without actual measuring.

The most difficult case is purposely selected. For if we assume that the bird has previously acquired an initial minimum speed of 17 miles an hour (24.93 feet per second, nearly the lowest measured), and that the air was rising vertically 6 miles an hour (8.80 feet per second), then we have as the trend of the "relative wind" encountered:

$$\frac{6}{17} = 0.353, \text{ or the tangent of } 19^\circ\ 26'$$

which brings the case into the category of rising wind effects. But the bird was observed to have a negative angle to the horizon of about 3°, as near as could be guessed, so that his angle of incidence to the "relative wind" was reduced to 16° 26′.

The relative speed of his soaring was therefore:

$$\text{Velocity} = \sqrt{17^2 + 6^2} = 18.03 \text{ miles per hour.}$$

At this speed, using the Langley coefficient recently practically confirmed by the accurate experiments of Mr. Eiffel, the air pressure would be:

$$18.03^2 \times 0.00327 = 1.063 \text{ pounds per square foot.}$$

If we apply Lilienthal's coefficients for an angle of $16° 26'$, we have for the force in action:

Normal: $4.57 \times 1.063 \times 0.912 = 4.42$ pounds.

Tangential: $4.57 \times 1.063 \times 0.074 = -0.359$ pounds.

Which latter, being negative, is a propelling force.

Thus we have a bird weighing 4.25 pounds not only thoroughly supported, but impelled forward by a force of 0.359 pounds, at 17 miles per hour, while the experiments of Prof. A. F. Zahm showed that the resistance at 15.52 miles per hour was only 0.27 pounds, or $0.27 \times \dfrac{17^2}{15.52^2} = 0.324$ pounds, at 17 miles an hour.

These are astonishing results from the data obtained, and they lead to the inquiry whether the energy of the rising air is sufficient to make up the losses which occur by reason of the resistance and friction of the bird's body and wings, which, being rounded, do not encounter air pressures in proportion to their maximum cross-section.

We have no accurate data upon the coefficients to apply, and estimates made by myself proved to be much smaller than the 0.27 pounds resistance measured by Professor Zahm, so that we will figure with the latter as modified. As the speed is 17 miles per hour, or 24.93 feet per second, we have for the work:

Work done, $0.324 \times 24.93 = 8.07$ foot-pounds per second.

Corresponding energy of rising air is not sufficient at 4 miles per hour. This amounts to but 2.10 foot-pounds per second, but if we assume that the air was rising at the rate of 7 miles per hour (10.26 feet per second), at which the pressure with the Langley coefficient would be 0.16 pounds per square foot, we have on 4.57 square feet for energy of rising air: $4.57 \times 0.16 \times 10.26 = 7.50$ foot-pounds per second, which is seen to be still a little too small, but well within the limits of error, in view of the hollow shape of the bird's wings, which receive greater pressure than the flat planes experimented upon by Langley.

These computations were chiefly made in January, 1899, and were communicated to a few friends, who found no fallacy in them, but thought that few aviators would understand them if published. They were then submitted to Prof. C. F. Marvin of the Weather Bureau, who is well known as a skilful physicist and mathematician. He wrote that they were, theoretically, entirely sound and quantitatively, probably, as accurate

as the present state of the measurements of wind pressures permitted. The writer determined, however, to withhold publications until the feat of soaring flight had been performed by man, partly because he believed that, to ensure safety, it would be necessary that the machine should be equipped with a motor in order to supplement any deficiency in wind force.

The feat would have been attempted in 1902 by Wright Brothers if the local circumstances had been more favorable. They were experimenting on "Kill Devil Hill," near Kitty Hawk, N.C. This sand hill, about 100 feet high, is bordered by a smooth beach on the side whence comes the sea breezes but has marshy ground at the back. Wright Brothers were apprehensive that if they rose on the ascending current of air at the front and began to circle like the birds, they might be carried by the descending current past the back of the hill and land in the marsh. Their gliding machine offered no greater head resistance in proportion than the buzzard, and their gliding angles of descent are practically as favorable, but the birds performed higher up in the air than they.

Professor Langley said in concluding his paper upon "The Internal Work of the Wind":

"The final application of these principles to the art of aerodromics seems, then, to be, that while it is not likely that the perfected aerodrome will ever be able to dispense altogether with the ability to rely at intervals on some internal source of power, it will not be indispensable that this aerodrome of the future shall, in order to go any distance — even to circumnavigate the globe without alighting — need to carry a weight of fuel which would enable it to perform this journey under conditions analogous to those of a steamship, but that the fuel and weight need only be such as to enable it to take care of itself in exceptional moments of calm."

Now that dynamic flying machines have been evolved and are being brought under control, it seems to be worth while to make these computations and the succeeding explanations known, so that some bold man will attempt the feat of soaring like a bird. The theory underlying the performance in a rising wind is not new, it has been suggested by Penaud and others, but it has attracted little attention, because the exact data and the maneuvers required were not known and the feat had not yet been performed by a man. The puzzle has always been to account for the observed act in very light winds, and it is hoped that by the present selection of the most difficult case

to explain — *i.e.*, the soaring in a dead horizontal calm — somebody will attempt the exploit.

The following are deemed to be the requisites and maneuvers to master the secrets of soaring flight:

1st. Develop a dynamic flying machine weighing about one pound per square foot of area, with stable equilibrium and under perfect control, capable of gliding by gravity at angles of one in ten ($5\frac{3}{4}°$) in still air.

2d. Select locations where soaring birds abound and occasions where rising trends of gentle winds are frequent and to be relied on.

3d. Obtain an initial velocity of at least 25 feet per second before attempting to soar.

4th. So locate the center of gravity that the apparatus shall assume a negative angle, fore and aft, of about 3°. Calculations show, however, that sufficient propelling force may still exist at 0°, but disappears entirely at + 4°.

5th. Circle like the bird. Simultaneously with the steering, incline the apparatus to the side toward which it is desired to turn, so that the centrifugal force shall be balanced by the centripetal force. The amount of the required inclination depends upon the speed and on the radius of the circle swept over.

6th. Rise spirally like the bird. Steer with the horizontal rudder, so as to descend slightly when going with the wind and to ascend when going against the wind. The bird circles over one spot because the rising trends of wind are generally confined to small areas or local chimneys, as pointed out by Sir H. Maxim and others.

7th. Once altitude is gained, progress may be made in any direction by gliding downward by gravity.

The bird's flying apparatus and skill are as yet infinitely superior to those of man, but there are indications that within a few years the latter may evolve more accurately proportioned apparatus and obtain absolute control over it.

It is hoped, therefore, that if there be found no radical error in the above computations, they will carry the conviction that soaring flight is not inaccessible to man, as it promises great economies of motive power in favorable localities of rising winds.

The writer will be grateful to experts who may point out any mistake committed in data or calculations, and will furnish additional information to any aviator who may wish to attempt the feat of soaring.

[From Aero. Ann., 1895.]

DARWIN'S OBSERVATIONS.

UNDER the date of April 27, 1834, in his journal[1] kept during the voyage of the "Beagle" round the world, Mr. Darwin, after considering the manner in which vultures[2] find their food, writes as follows:

"Often when lying down to rest on the open plains, on looking upwards I have seen carrion-hawks sailing through the air at a great height. Where the country is level I do not believe a space of the heavens of more than fifteen degrees above the horizon is commonly viewed with any attention by a person either walking or on horseback. If such be the case, and the vulture is on the wing at a height of between three and four thousand feet, before it could come within the range of vision, its distance in a straight line from the beholder's eye would be rather more than two British miles. Might it not thus readily be overlooked? When an animal is killed by the sportsman in a lonely valley, may he not all the while be watched from above by the sharp-sighted bird? And will not the manner of its descent proclaim throughout the district to the whole family of carrion-feeders that their prey is at hand?

"When the condors are wheeling in a flock round and round any spot, their flight is beautiful. Except when rising from the ground, I do not recollect ever having seen one of these birds flap its wings. Near Lima, I watched several for nearly half an hour without once taking off my eyes. They moved in large curves, sweeping in circles, descending and ascending without giving a single flap. As they glided close over my head, I

[1] A Naturalist's Voyage. Journal of Researches into the Natural History and Geology of the countries visited during the voyage of H.M.S. "Beagle" round the World. By Charles Darwin, M.A., F.R.S. London. 1845.

intently watched from an oblique position the outlines of the separate and great terminal feathers of each wing; and these separate feathers, if there had been the least vibratory movement, would have appeared as if blended together; but they were seen distinct against the blue sky.

"The head and neck were moved frequently, and apparently with force; and the extended wings seemed to form the fulcrum on which the movements of the neck, body, and tail acted. If the bird wished to descend, the wings were for a moment collapsed; and when again expanded with an altered inclination, the momentum gained by the rapid descent seemed to urge the bird upwards with the even and steady movement of a paper kite. In the case of any bird *soaring*, its motion must be sufficiently rapid, so that the action of the inclined surface of its body on the atmosphere may counterbalance its gravity. The force to keep up the momentum of a body moving in a horizontal plane in the air (in which there is so little friction) cannot be great, *and this force is all that is wanted.*

"The movement of the neck and body of the condor, we must suppose, is sufficient for this. However this may be, it is truly wonderful and beautiful to see so great a bird, hour after hour, without any apparent exertion, wheeling and gliding over mountain and river."

[From Aero. Ann., 1896.]

HOW A BIRD SOARS.

By Professor William H. Pickering, of Harvard Observatory.

By "soaring" is meant the upward spiral progress of a bird, without apparent muscular effort. This action may be observed in this part of the world to particular advantage, in the case of certain large hawks. The following explanation of the principle of soaring is extracted from an article which I published in "Science," 1889, p. 245, and is, I believe, the first description of the process which ascribes to gusts of wind their true influence in the production of the phenomenon:

"Whenever there is a high wind, such as is undoubtedly required by a soaring bird, we know that the air pressure is not uniform, that the wind comes in gusts. Those familiar with mountain summits know that the same phenomena are observed in the upper atmosphere as at the surface of the ground. If we were travelling along with such a wind in a balloon, the gusts would not be so severe, but they would be of longer duration.

A ———————————————— B

"Imagine, now, a bird travelling from A to B, in the same direction as the wind, and with its mean velocity. When the wind is uniform, it seems to him that he is in a dead calm. When a gust comes, the wind seems to blow from A. It carries him along faster; and when it ceases the wind seems to blow from B. It therefore affects him precisely as if he were in an alternating current of wind.

"Suppose, now, that he is drifting towards B with a velocity equal to that of the wind, and travelling at right angles to AB with such a velocity that he can move along horizontally without falling towards the earth. Suddenly a gust overtakes him

from the direction of A. He at once turns towards it, and his velocity relative to it is sufficient to raise him in the air. It tends to carry him more rapidly towards B; and when his velocity relative to it has sunk to the same value as before, and he again travels horizontally, he turns again at right angles to the line AB, but in the opposite direction to that which he had before. Presently the force of the gust diminishes, and the wind seems to blow towards him from the direction B. He accordingly turns toward it again, rising from the ground till his velocity relative to the air has assumed its former value, and he moves horizontally, turning again at right angles to the line AB, and the cycle is completed. He thus moves along in the direction AB with a mean velocity equal to that of the wind, rising when moving parallel to it, and moving horizontally, or perhaps slowly falling, if the gusts do not come with sufficient frequency, when moving at right angles to it.

"In the case of all soaring birds, the spread tail, being an inclined curved surface, presents a large area to the wind. As it is situated at a considerable distance from the bird's centre of gravity, it must convert him into a sort of floating weather-cock, the wings serving as dampers to restrain him from turning too quickly. It therefore appears, if soaring really does depend on the interaction of varying wind-currents, as if the changes of direction involved must be almost automatic, and not a thing which the bird is required to learn; although he may doubtless learn to take advantage of favoring currents by giving proper inclinations to his wings and tail.

"If the question be raised as to the sufficiency of the varying intensity of the wind-currents to maintain the bird's initial velocity against the resistance of the air, we must reply that it is a matter which can only be determined conclusively by experiment. Certain it is, however, that in windy weather the wind does come in gusts. If in the course of his circles the bird happens to be travelling at right angles to the wind, when the gust strikes him he will surely be turned round, almost in spite of himself, so as to face the gust. If the bird does face the gust, it will certainly raise him to a higher level.

"If this explanation proves to be the true one, the reason why small birds cannot soar is probably, that, in those of them that have suitably shaped wings and bodies, their surfaces are so large in proportion to their weights that they rapidly assume the velocity of the surrounding air. In order that they might soar to advantage, the gusts should come more frequently, and be of shorter duration, than we actually find to occur in nature."

Obviously, if the mean velocity of the wind is high, and the gusts comparatively insignificant, the bird may rise without difficulty, but he will drift rapidly along in the direction towards which the wind is blowing. Let us now imagine the conditions reversed; let the mean velocity of the wind be very low, while the gusts are of great intensity. The bird will now rise rapidly, and may then take advantage of his position to soar downwards against the wind, not merely holding his own, but even advancing against it. We thus see how it would be theoretically possible upon a windy day for a bird to travel at will in any desired direction without making the slightest mechanical exertion whatever, and also without taking advantage of any upward currents that might exist. That these currents do exist in certain localities, especially in hilly districts, and that they are often used by the birds almost like stairways there now seems no reason to doubt. That such upward currents are not absolutely necessary, however, for purposes of soaring, it is the object of this article to point out.

Soon shall thy arm, unconquered steam, afar
Drag the slow barge, or drive the rapid car;
Or on wide waving wings expanded bear
The flying chariot through the field of air.

— ERASMUS DARWIN, d. 1802.

[From AERO. ANN., 1896.]

NATURAL AND ARTIFICIAL FLIGHT.

By HIRAM S. MAXIM.

I.

INTRODUCTORY.

AT the time I commenced my experiments in aeronautics it was not generally believed that it would ever be possible to make a large machine heavier than the air that would lift itself from the earth by dynamic energy generated by the machine itself. It is true that a great number of experiments had been made with balloons, but these are in no sense true flying machines. Every one who attempted a solution of the question by machines heavier than the air, was looked upon in very much the same light as the man is now who attempts to construct a perpetual motion machine. Up to within a few years, nearly all experiments in aerial navigation by flying machines have been made by men not versed in science, and who for the most part have been ignorant of the most rudimentary laws of dynamics. It is only quite recently that scientific engineers have

taken up the question and removed it from the hands of charlatans and mountebanks. A few years ago many engineers would not have dared to face the ridicule which they would be liable to receive if they had asserted that it would be possible to make a machine that would lift itself by mechanical means into the air. However, thanks to the admirable work of Professor Langley, Professor Thurston, Mr. Chanute and others, one may now express his opinion freely on this subject and speculate as to the possibilities of making flying machines, without being relegated to the realm of cranks and fanatics.

During the last five years I have had occasion to write a large number of articles for the public press on this subject, and I have always attempted, as far as it is in my power, to discuss the subject in such a manner as to be easily understood by the unscientific, and I believe that my efforts have done something in the direction of popularizing the idea that it is possible to construct practical flying machines.

In preparing my present work, I have aimed as far as possible to discuss the question in plain and simple language, and to abstain from the use of any formulæ which may not be understood by every one. It has been my experience that if a work abounds in formulæ and tables, even only a few of the scientific will take the trouble to read or understand it. I have therefore confined myself to a plain statement of the actual facts, describing the character of my observations and experiments, and giving the results of the same. All experiments made by others in the same direction have been on a very small scale, and, as a rule, the apparatus employed has been made to travel around a circle, the size of which has not been great enough to prevent the apparatus continually encountering air which had been influenced in some way by the previous revolution.

The first experiments which I conducted were with an apparatus which travelled around a circle 200 feet in circumference, and by mounting some delicate anemometers directly under the path of the apparatus I ascertained that after it had been travelling at a high velocity for a few seconds, there was a well-

defined air current blowing downward around the whole circle, so that my planes in passing forward must have been influenced and their lifting effect reduced to some extent by this downward current. My late experiments are the first which have ever been made with an apparatus on a large scale moving in a straight line. In discussing the question of aerial flight with Professor Langley before my large experiments had been made, the Professor suggested that there might be some unknown factor relating to size only which might defeat my experiments, and that none of our experiments had at that time been on a sufficiently large scale to demonstrate what the lifting effect of very large planes would be. A flying machine to be of any value must of necessity be large enough to carry at least one man, and the larger the machine the smaller the factor of the man's weight. Moreover, it is possible to make engines of say from 200 to 400 horse-power, lighter per unit of power than very small engines of from one to two horse-power. On the other hand, it is not advisable to construct a machine on too large a scale, because as the machine becomes larger the relative strength of the material becomes less. In first designing my large machine I intended that it should weigh about 5,000 pounds without men, water, or fuel, that the screw thrust should be 1,500 pounds, and that the total area of the planes should be 5,000 square feet. I expected to lift this machine and drive it through the air at a velocity of 35 miles an hour with an expenditure of about 250 horse-power. However, upon completing the machine I found that many parts were too weak, and these had to be supplanted by thicker and stronger material. This increased the weight of the machine about 2,000 pounds. Upon trying my engines I found that if required they would develop 360 horse-power, and that a screw thrust of over 2,000 pounds could be easily attained, but as an offset against this, the amount of power required for driving the machine through the air was a good deal more than I had anticipated.

NOTE.—For Mr. Maxim's description of this machine see "Century Magazine," N.Y., January, 1895.

II.

NATURAL FLIGHT.

During the last 50 years a great deal has been said and written in regard to the flight of birds. Perhaps no other natural phenomenon has excited so much interest and has been so little understood. Learned treatises have been written to prove that a bird is able to develop from 10 to 100 times as much power for its weight as other animals, while other equally learned treatises have shown most conclusively that no greater amount of energy is exerted by a bird in flying than by land animals in running or jumping.

There is no question but what a bird has a higher physical development, as far as the generation of power is concerned, than any other animal we know of. Nevertheless, I think that every one who has made a study of the question will agree that some animals, such as rabbits, exert quite as much power in running in proportion to their weight as a sea-gull or an eagle exerts in flying.

The amount of power which a land animal has to exert is always a fixed and definite quantity. If an animal weighing 100 pounds has to ascend a hill 100 feet high, it always means the development of 10,000 foot-pounds. With a bird, however, there is no such thing as a fixed quantity, because the medium in which the bird is moving is never stationary. If a bird weighing 100 pounds should raise itself into the air 100 feet during a perfect calm, the amount of energy developed would be 10,000 foot-pounds plus the slip of the wings. But, as a matter of fact, the air in which a bird flies is never stationary, as I propose to show; it is always moving either up or down, and soaring birds, by a very delicate sense of feeling, always take advantage of a rising column of air. If a bird finds itself in a column of air which is descending, it is necessary for it to work its wings very rapidly in order to prevent a descent to the earth.

I have often observed the flight of hawks and eagles. They

seem to glide through the air with hardly any movement of their wings. Sometimes, however, they stop and hold themselves in a stationary position directly over a certain spot, carefully watching something on the earth immediately below. In such cases they often work their wings with great rapidity, evidently expending an enormous amount of energy. When, however, they cease to hover and commence to move again through the air, they appear to keep themselves at the same height with an almost imperceptible expenditure of force.

Many unscientific observers of the flight of birds have imagined that a wind or a *horizontal* movement of the air is all that is necessary in order to sustain the weight of a bird in the air after the manner of a kite. If, however, the wind, which is only air in motion, should be blowing everywhere at exactly the same speed and in the same direction (horizontally), it would offer no more sustaining power to a bird than a dead calm, because there is nothing to prevent the body of the bird being blown along with the air, and whenever it had attained the same velocity as the air, no possible arrangement of the wings would prevent it from falling to the earth.

The wind, however, seldom or never blows in a horizontal direction. Some experimenters have lately asserted that if it were possible for us to ascend far enough, we should find the temperature constantly falling until at about 20 or 25 miles above the earth's surface the absolute zero might be reached. Now, as the air near the earth never falls in temperature to anything like the absolute zero, it follows that there is a constant change going on, the relatively warm air near the surface of the earth always ascending, and, in some cases, doing sufficient work in expanding to render a portion of the water it contains visible, forming clouds, rain, or snow, while the very cold air is constantly descending to take the place of the rising column of warm air.

On one occasion while crossing the Atlantic in fine weather, I noticed, some miles directly ahead of the ship, a long line of glassy water. Small waves indicated that the wind was blowing in the exact direction in which the ship was moving, and I

observed as we approached the glassy line that the waves became smaller and smaller until they completely disappeared in a mirror-like surface which was about 300 or 400 feet wide and extended both to the port and starboard in approximately a straight line as far as the eye could reach. After passing the centre of this zone, I noticed that small waves began to show themselves, but in the exact opposite direction to those through which we had already passed. I observed that these waves became larger and larger for nearly an hour. Then they began to get gradually smaller, when I observed another glassy line directly ahead of the ship. As we approached it the waves completely disappeared, but after passing through it I noticed that the wind was blowing in the opposite direction and that the waves increased in size exactly in the same manner that they had diminished on the opposite side of the glassy zone.

This would seem to indicate that directly over the centre of the first glassy zone, the air was meeting from both sides and ascending, and that at the other glassy zone the air was descending in practically a straight line to the surface of the water where it spread out and set up a light wind in both directions.

I spent the winter of 1890–91 on the Riviera, between Hyères les Palmiers and Monte Carlo. The weather for the most part was very fine, and I often had opportunities of observing the peculiar phenomena which I had already noticed in the Atlantic, only on a much smaller scale. Whereas, in the Atlantic, the glassy zones were from 5 to 20 miles apart, I often found them not more than 500 feet apart in the bays of the Mediterranean.

At Nice and Monte Carlo this phenomenon was also very marked. On one occasion, while making observations from the highest part of the promontory of Monaco on a perfectly calm day, I noticed that the whole of the sea presented this peculiar effect as far as the eye could reach, and that the lines which marked the descending air were never more than a thousand feet from those which marked the centre of the ascending column. At about 3 o'clock in the afternoon, a large black steamer

passed along the coast in a perfectly straight line, and I noticed that its wake was at once marked by a glassy line which indicated the centre of an ascending column. This line remained almost straight for two hours, when finally it became crooked and broken. The heat of the steamer had been sufficient to determine this upward current of air.

In 1893, I spent two weeks in the Mediterranean, going by a slow steamer from Marseilles to Constantinople and returning, and I had many opportunities of observing the peculiar phenomenon which I have before referred to. The steamer passed over thousands of square miles of calm sea, the surface being only disturbed by large batches of small ripples separated from each other by glassy streaks, and I found that in no case was the wind blowing in the same direction on both sides of these streaks, every one of them either indicating the centre of an ascending or a descending column of air.

If we should investigate this phenomenon in what might be called a dead calm, we should probably find that the air was rising straight up over the centres of some of these streaks, and descending in a vertical line over the centres of the others. But, as a matter of fact, there is no such thing as a dead calm. The movement of the air is the resultant of more than one force. The air is not only rising in some places and descending in others, but at the same time the whole mass is moving forward with more or less rapidity from one part of the earth to another. So we might consider that, instead of the air ascending directly from the relatively hot surface of the earth and descending vertically in other places, in reality it is moving on an incline.

Suppose that the local influence which causes the up and down motion of the air should be sufficiently great to cause it to rise at the rate of 2 miles an hour, and that the wind at the same time should be blowing at the rate of 10 miles an hour; the motion of the air would then be the resultant of these two velocities. In other words, it would be blowing up an incline of 1 in 5. Suppose now, that a bird should be able to so adjust its wings that it advanced 5 miles in falling 1 mile through

a perfectly calm atmosphere; it would be able to sustain itself in an inclined wind, such as I have described, without any movement at all of its wings. If it was able to adjust its wings in such a manner that it could advance 6 miles by falling through 1 mile of air, it would then be able to rise as relates to the earth while in reality falling as relates to the surrounding air.

In conducting a series of experiments with artillery and small guns in a very large and level field just out of Madrid, I often observed the same phenomena as relates to the wind, that I have already spoken of as having observed at sea, except that the lines marking the centre of an ascending or a descending column of air were not so stationary as they were over the water. It was not an uncommon thing when adjusting the sights of a gun to fire at a target at very long range, making due allowances for the wind, to have the wind change and blow in the opposite direction before the word of command was given to fire. While conducting these experiments, I often noticed the flight of eagles. On one occasion a pair of eagles came into sight on one side of the plain, passed directly over our heads and disappeared on the opposite side. They were apparently always at the same height from the earth and soared completely across the plain without once moving their wings. This phenomenon, I think, can only be accounted for on the hypothesis that they were able to feel out with their wings an ascending column of air, that the centre of this column of air was approximately a straight line running completely across the plain, that they found the ascending column to be more than necessary to sustain their weight in the air, and that whereas, as relates to the earth, they were not falling at all, they were really falling some 2 or 3 miles an hour in the air which supported them.

Again, at Cadiz in Spain, when the wind was blowing in very strongly from the sea, I noticed that the sea-gulls always took advantage of an ascending column of air. As the wind blew in from the sea and rose to pass over the fortifications, the sea-gulls selected a place where they could slide down on the ascending current of air, keeping themselves always approxi-

mately in the same place without any apparent exertion. When, however, they left this ascending column, I observed that it was necessary for them to work their wings with great vigor until they again found the proper place to encounter the favorable current.

I have often noticed sea-gulls following a ship. I have observed that they are able to follow the ship without any apparent exertion; they simply balance themselves on an ascending column of air and seem to be quite as much at ease as they would be if they were roosting on a solid support. If, however, they are driven out of this position, I find that they generally have to commence at once to work their passage. If anything is thrown overboard which is too heavy for them to lift, the ship soon leaves them, and in order to catch up with it again, they move their wings very much as other birds do; but when once established in the ascending column of air, they manage to keep up with the ship by doing little or no work. In a head wind we find them directly aft of the ship; if the wind is from the port side, they may always be found on the starboard quarter, and *vice versa*.

Every one who has passed a winter on the northern shores of the Mediterranean must have observed the cold wind which is generally called the *mistral*. One may be out driving, the sun may be shining brightly, and the air be warm and balmy, when, suddenly, without any apparent cause, one finds himself in a cold descending wind. This is the much-dreaded mistral, and if at sea, it would be marked by a glassy line on the surface of the water. On land, however, there is nothing to render its presence visible. I have found that the ascending column of air is always very much warmer than the descending column, and that this action is constantly taking place in a greater or less degree.

From the foregoing deductions I think we may draw the following conclusions:

First, that there is a constant interchange of air taking place, the cold air descending, spreading itself out over the surface of the earth, becoming warm, and ascending in other places.

Second that the centres of the two columns are generally separated from each other by a distance which may be from 500 feet to 20 miles.

Third, that the centres of greatest action are not in spots, but in lines which may be approximately straight but generally abound in many sinuosities.

Fourth, that this action is constantly taking place over both the sea and the land, that the soaring of birds, a phenomenon which has heretofore been so little understood, may be accounted for on the hypothesis that the bird seeks out an ascending column of air, and that, while sustaining itself at the same height in the air without any muscular exertion, it is in reality falling at a considerable speed through the air that surrounds it.

It has been supposed by some scientists that the birds may take advantage of some vibratory or rolling action of the air. I find, however, from careful observation and experiment, that the motion of the wind is comparatively steady, and that the short vibratory or rolling action is always very near to the earth and is produced by the air flowing over the tops of hills, high buildings, or trees. If a kite is flown only a few feet above the ground, it will be found that the current of air is very unsteady. If it is allowed to mount to 500 feet, the unsteadiness nearly all disappears, while if it is further allowed to mount to a height of 1,500 or 2,000 feet, the pull on the cord is almost constant, and, if the kite is well made, it remains practically stationary in the air.

I have often noticed in high winds, that light and fleecy clouds come into view, say, about 2,000 feet above the surface of the earth, and that they pass rapidly and steadily by, preserving their shape completely. This would certainly indicate that there is no rapid local disturbance in the air in their immediate vicinity, but that the whole mass of air in which these clouds are formed is practically travelling in the same direction and at the same velocity. Numerous aeronauts have also testified that, no matter how hard the wind may be blowing, the balloon is always practically in a dead calm, and if a piece of gold-leaf is

thrown overboard even in a gale, the gold-leaf and the balloon never part company in a horizontal direction, though they may in a vertical direction.

Birds may be divided into two classes: first, the soaring birds, which practically live upon the wing, and which, by some very delicate sense of touch, are able to feel the exact condition of the air. Many fish which live near the top of the water are greatly distressed by sinking too deeply, while others which live at great depths are almost instantly killed by being raised to the surface. The swim bladder of a fish is in reality a delicate barometer provided with sensitive nerves which enable the fish to feel whether it is sinking or rising in the water. With the surface fish, if the pressure becomes too great, the fish involuntarily exerts itself to rise nearer the surface and so diminish the pressure, and I have no doubt that the air-cells, which are known to be very numerous and to abound throughout the bodies of birds, are so sensitive as to enable soaring birds to know at once whether they are in an ascending or a descending column of air.

The other class of birds consists of those which only employ their wings for the purpose of taking them rapidly from one place to another. Such birds may be considered not to expend their power so economically as the soaring birds. They do not spend a very large portion of their time in the air, but what time they are on the wing they exert an immense amount of power and fly very rapidly, generally in a straight line, taking no advantage of air currents. Partridges, pheasants, wild ducks, geese, and some birds of passage may be taken as types of this kind. This class of birds has relatively small wings, and carries about 2½ times as much weight per square foot of surface as soaring birds do.

III.

ARTIFICIAL FLIGHT. — THE ENGINES.

There is no question but what birds — and, for that matter, all animals — when considered as thermo-dynamic machines,

are very perfect motors; they develop the full theoretical amount of energy in the carbon consumed. This we are quite unable to do with any artificial machine, but birds for the most part have to content themselves with food which is not very rich in carbon. It is quite true that a bird may develop from 10 to 15 times as much power from the carbon consumed as may be developed by the best steam-engine, but as an offset against this, a steam-engine is able to consume petroleum, which has at least 20 times as many thermal units per pound as the ordinary food of birds. The movement of a bird's wings, from long years of development, has without doubt attained a great degree of perfection. Birds are able to scull themselves through the air with very little loss of energy. To imitate by mechanical means the exact and delicate motion of their wings would certainly be a very difficult task, and I do not believe that we should attempt it in constructing an artificial flying machine. In Nature it is necessary that an animal should be made all in one piece. It is therefore quite out of the question that any part or parts should revolve. For land animals there is no question but what legs are the most perfect system possible, but in terrestrial locomotion by machinery — not necessarily in one piece — the wheel is found to be much more effective and efficient. The swiftest animal can only travel for a minute of time at half the speed of a locomotive, while the locomotive is able to maintain its much greater speed for many hours at a time. The largest land animals only weigh about 5 tons, while the largest locomotives weigh from 60 to 80 tons. In the sea, the largest animal weighs about 75 tons, while the ordinary Atlantic liner weighs from 4,000 to 14,000 tons. The whale no doubt is able to maintain a high speed for several hours at a time, but the modern steamer is able to maintain a still higher speed for many consecutive days.

As artificial machines for terrestrial and aquatic locomotion have been made immensely stronger and larger than land or water animals, so, in a flying machine, it will be necessary to construct it much heavier and stronger than the largest bird. If one should attempt to propel such a machine with wings, it

would be quite as difficult a problem to solve as it would be to make a locomotive that would walk on legs. What is required in a flying machine is something to which a very large amount of power can be directly and continuously applied without any intervening levers or joints, and this we find in the screw propeller.

It was about 20 years ago that I first commenced to think of the question of artificial flight. My first idea was to construct a machine with two large screws on vertical shafts. I proposed to run these screws in reverse directions by the use of a caloric or hot-air engine, but after considering the subject for some time, I came to the conclusion that this class of engine would not do. When the Brayton gas engine first made its appearance, I commenced drawings of a machine, using a modification of the Brayton motor which I designed expressly for the purpose; but even this was found to be too heavy, and it was not until after I abandoned the vertical screw system that it was possible for me to design a machine which in theory ought to fly.

The next machine which I considered was on the kite or aeroplane system. This was also to be driven by an oil engine. Oil engines at that time were not so simple as now, and moreover the system of ignition was very heavy, cumbersome, and uncertain. Since that time, however, gas and oil engines have been very much improved, and the ignition tube, which is almost universally used, has greatly simplified the ignition, so that at the present time I am of the opinion that an oil engine might be designed which would be suitable for the purpose.

IV.

THE ADVANTAGES AND DISADVANTAGES OF VERY NARROW PLANES.

My experiments have demonstrated that relatively narrow aeroplanes lift more per square foot than very wide ones, but as an aeroplane, no matter how narrow it may be, must of neces-

sity have some thickness, it is not advantageous to place them too near together. Suppose that aeroplanes should be made $\frac{1}{4}$ in. thick and be superposed 3 inches apart, that is, at a pitch of 3 inches. One-twelfth part of the whole space through which these planes would have to be driven would be occupied by the planes themselves, and eleven-twelfths would be air space (Fig. 1). If a group of planes thus mounted should be driven through the air at the rate of 36 miles an hour,[1] the air would have to be driven forward at the rate of 3 miles an hour, or else it would have to be compressed, or spun out, and pass between the spaces at a speed of 39 miles an hour. As a matter of fact, however, the difference in pressure is so very small, that practically no atmospheric compression takes place. The air, therefore, is driven forward at the rate of 3 miles an hour, and this consumes a great deal of power, in fact, so much that there is a decided disadvantage in using narrow planes thus arranged.

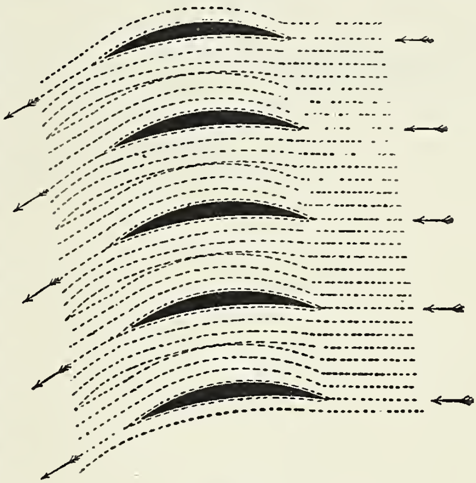


Fig. 1.

In regard to the curvature of narrow aeroplanes, I have found that if one only desires to lift a large load in proportion to the area, the planes may be made very hollow on the underneath side; but when one considers the lift in terms of screw thrust, I find it advisable that the planes should be as thin as possible and the underneath side nearly flat. I have also found that it is a great advantage to arrange the planes after the manner

[1] The arrows in the accompanying drawings show the direction of the air currents, the experiments having been made with stationary planes and a moving current of air.

shown in Fig. 2. In this manner, the sum of all the spaces between the planes is equal to the whole area occupied by the

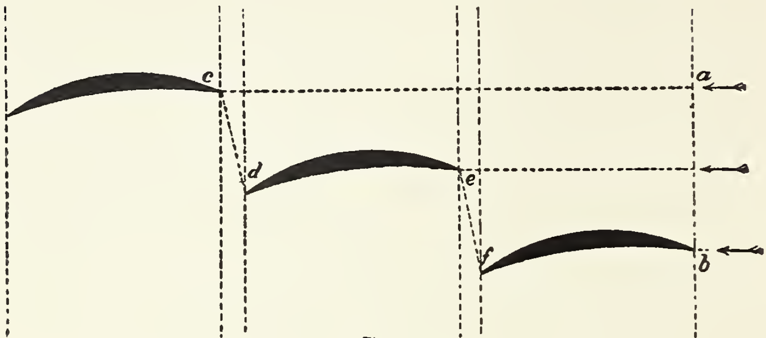


Fig. 2.

planes; consequently, the air neither has to be compressed, spun out, or driven forward. I am therefore by this arrangement able to produce a large lifting effect per square foot, and, at the same time, to keep the screw thrust within reasonable limits.

A large number of experiments with very narrow aeroplanes have been conducted by Mr. Horatio Phillips at Harrow, in England. Fig. 3 shows a cross section of one of Mr. Phillips' planes. Mr. Phillips is of the opinion that the air in striking the top side of the plane is thrown upward in the manner shown and a partial vacuum is thereby formed over the central part of the plane, and that the lifting effect of planes made in this form is therefore very much greater than with ordinary narrow planes. I have experimented with these "sustainers" (as Mr. Phillips calls them) myself, and I find it is quite true that they lift in some cases as much as 8 lb. per sq. ft.,[1] but the lifting effect is not

Fig. 3.

[1] In my early experiments I lifted as much as 8 lb. per sq. ft. with aeroplanes which were only slightly curved, but very thin and sharp.

produced in the exact manner that Mr. Phillips seems to suppose. The air does not glance off in the manner shown. As the "sustainer" strikes the air, two currents are formed, one following the exact contour of the top and the other the bottom. These two currents join and are thrown downward as relates to the "sustainer" at an angle which is the resultant of the angles at which the two currents meet. (Fig. 4.) These

Fig. 4.

"sustainers" may be made to lift when the front edge is lower than the rear edge because they encounter still air, and leave it with a downward motion.

In my experiments with narrow superposed planes, I have always found that with strips of thin metal made sharp at both edges and only slightly curved, the lifting effect, when considered in terms of screw thrust, was always greater than with any arrangement of the wooden aeroplanes used in Phillips' experiments. It would therefore appear that there is no advantage in the peculiar form of "sustainer" employed by this inventor.

If an aeroplane be made perfectly flat on the bottom side and convex on the top, as shown in Fig. 5, and be mounted in the air so that the bottom side is exactly horizontal, it produces a lifting effect no matter in which direction it is run, because as it advances it encounters stationary air which is divided into two streams. The top stream being unable to fly off at a tangent when turning over the top curve, flows down the incline and joins the current which is flowing over the lower horizontal surface. The angle at which the combined stream of air leaves the plane is the resultant of these two angles; consequently, as the plane finds the air in a stationary condition and leaves it with a downward motion, the plane itself must be lifted. It is

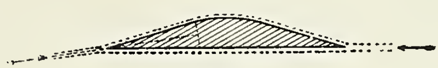


Fig 5.

true that small and narrow aeroplanes may be made to lift considerably more per square foot of surface than very large ones, but they do not offer the same safeguard against a rapid descent to the earth in case of a stoppage or breakdown of the machinery. With a large aeroplane properly adjusted, a rapid and destructive fall to the earth is quite impossible.

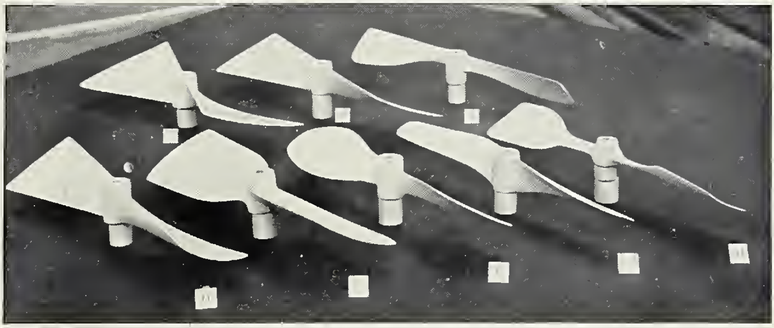
In the foregoing experiments with narrow aeroplanes, I employed an apparatus which enabled me to mount my planes at any angle in a powerful blast of air, and to weigh the exact lifting effect and also the tendency to drift with the wind. This apparatus also enables me to determine with a great degree of nicety the best form of an atmospheric condenser to employ.

V.

THE EFFICIENCY OF SCREW PROPELLERS. — STEERING, STABILITY, ETC.

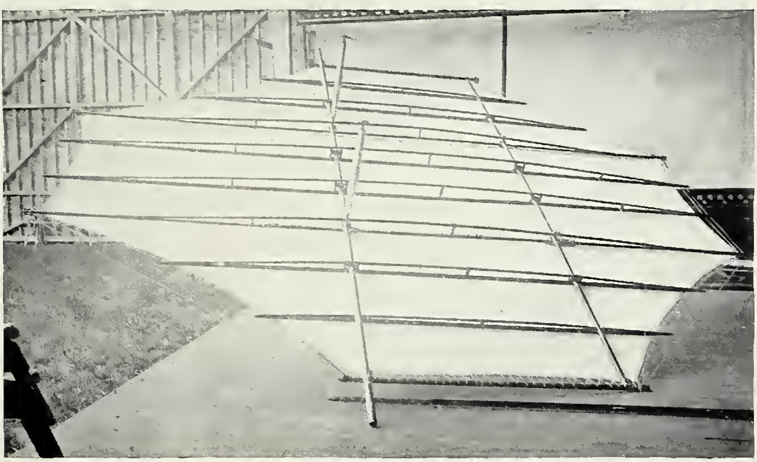
Before I commenced my experiments at Baldwyn's Park, I attempted to obtain some information in regard to the action of screw propellers working in the air. I went to Paris and saw the apparatus which the French Government employed for testing the efficiency of screw propellers, but the propellers were so very badly made that the experiments were of no value. Upon consulting an English experimenter who had made a "lifelong study" of the question, he assured me that I should find the screw propeller very inefficient and very wasteful of power. He said that all screw propellers had a powerful fan-blower action, drawing in air at the centre and discharging it with great force at the periphery. I found that no two men were agreed as to the action of screw propellers. All the data or formulæ available were so confusing and contradictory as to be of no value whatsoever. Some experimenters were of the opinion that in computing the thrust of a screw we should only consider the projected area of the blades, and that the thrust would be equal

K J I



H G F E D

A group, showing the various forms of screws which Mr. Maxim has tested. The screw J was found to be the most efficient. A similar screw K, with wider blades, did not do so well. The screw E, although very light and small, did very well. G, a screw made on the French plan, proved the worst screw experimented with. H, the same form as J, except that the blades are much thicker, also did remarkably well.



THE FORWARD RUDDER FOR STEERING MR. MAXIM'S MACHINE IN A VERTICAL DIRECTION.

This plate is especially interesting as showing the construction of the framing. — Ed.

to a wind blowing against a normal plane of equal area at a velocity equal to the slip. Others were of the opinion that the whole screw disk would have to be considered; that is, that the thrust would be equal to a wind blowing against a normal plane equal to the area of the whole disk at the velocity of the slip. The projected area of the two screw blades of my machine is 94 square feet, and the area of the 2 screw disks is 500 square feet. According to the first system of reasoning, therefore, the screw thrust of my large machine, when running at 40 miles an hour with a slip of 18 miles per hour, would have been, according to the well-known formula, $V^2 \times .005 = P$

$$18^2 \times .005 \times 94 = 152.28 \text{ pounds.}$$

If, however, we should have considered the whole screw disk, it would have been —

$$18^2 \times .005 \times 500 = 810 \text{ pounds.}$$

However, when the machine was run over the track at this rate, the thrust was found to be rather more than 2,000 lbs. When the machine was secured to the track and the screws revolved until the pitch in feet multiplied by the turns per minute was equal to 68 miles an hour, it was found that the screw thrust was 2,164 lbs. In this case it was of course all slip, and when the screws had been making a few turns they had established a well-defined air-current, and the power exerted by the engines was simply to maintain this air-current, and it is interesting to note that if we compute the projected area of these blades by the foregoing formula, the thrust would be —

$$68^2 \times .005 \times 94 = 2173.28 \text{ pounds,}$$

which is almost exactly the observed screw thrust. From this, it would appear when the machine is stationary, and all the power is consumed in slip, that only the projected area of the screw blades should be considered. But whenever the machine is allowed to advance, and to encounter new air, the inertia of which has not been disturbed, the efficiency increases in geometrical progression. The exact rate for all speeds I have not yet ascertained. My experiments have, however, shown that with a speed of 40 miles an hour and a screw slip of 18 miles an hour, a well-made screw

propeller is 13.1 times as efficient as early experimenters had supposed and attempted to prove by elaborate formulæ.

When I first commenced my experiments with a large machine, I did not know exactly what form of boiler, gas generator, or burner I should finally adopt; I did not know the exact size that it would be necessary to make my engines; I did not know the size, the pitch, or the diameter of the screws which would be the most advantageous. Neither did I know the form of aeroplane which I should finally adopt. It was therefore necessary for me to make the foundation or platform of my machine of such a character that it would allow me to make the modifications necessary to arrive at the best results. The platform of the machine is therefore rather larger than is necessary, and I find if I were to design a completely new machine, that it would be possible to greatly reduce the weight of the framework, and, what is still more, to greatly reduce the force necessary to drive it through the air.

At the present time, the body of my machine [1] is a large platform, about 8 ft. wide and 40 ft. long. Each side is formed of very strong trusses of steel tubes, braced in every direction by strong steel wires. The trusses which give stiffness to this superstructure are all below the platform. In designing a new machine, I should make the trusses much deeper and at the same time very much lighter, and, instead of having them below the platform on which the boiler is situated, I should have them constructed in such a manner as to completely enclose the boiler and the greater part of the machinery. I should make the cross-section of the framework rectangular, and pointed at each end. I should cover the outside very carefully with balloon material, giving it a perfectly smooth and even surface throughout, so that it might be easily driven through the air.

In regard to the screws, I am at the present time able to mount screws 17 ft. 10 in. in diameter. I find, however, that my machine would be much more efficient if the screws were 24 feet in diameter, and I believe with such very large screws, four blades would be much more efficient than two.

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[1] See *A New Flying Machine*, by H. S. Maxim. Century Magazine, N. Y., January, 1895. — *Ed.*

My machine may be steered to the right or to the left by running one of the propellers faster than the other. Very convenient throttle valves have been provided to facilitate this system of steering. An ordinary vertical rudder placed just after the screws may, however, prove more convenient, if not more efficient.

The machine is provided with fore and aft horizontal rudders, both of which are connected with the same windlass. If the forward rudder is placed at an angle considerably greater than that of the main aeroplane, and the rear rudder placed flat so as not to lift at all (Fig. 7), and the machine run over the track at a high speed, the front wheels will be lifted from the steel rails, leaving the rear wheels on the rails. If the rudders are placed in the reverse position so that the front rudder is thrown out of action, and the rear rudder lifts to its full extent (Fig. 8), the hind wheels will be lifted from the steel rails, leaving only the forward wheels touching. If both rudders are placed at such an angle that they both lift (Fig. 9), and the machine is run at a very high velocity, all four of the wheels will be lifted from the steel rails. This would seem to show that these rudders are efficient as far as vertical steering is concerned. If the machine should break down in the air it would be necessary to tilt the rudders in the position shown in Fig. 10, when it would fall to the ground without pitching or diving.

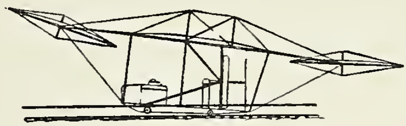


Fig. 7. — The forward wheels off the track.

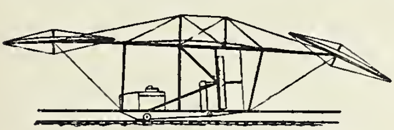


Fig. 8. — The rear wheels off the track.

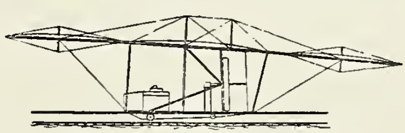


Fig. 9. — All the wheels off the track.

In regard to the stability of the machine, the centre of weight

is much below the centre of lifting effect; moreover, the upper wings are set at such an angle that whenever the machine tilts to the right or to the left, the lifting effect is increased on the lower side and diminished on the higher side (Fig. 11). This simple arrangement makes the machine automatic as far as rolling is concerned. I am of the opinion that whenever flying machines come into use it will be necessary to steer them in a vertical direction by means of an automatic steering gear controlled by a gyroscope. It will certainly not be more difficult to manœuvre and steer such machines than it is to control completely submerged torpedoes.

Fig. 10. — Showing the manner of placing the fore and aft rudders in case of a breakage of the machinery.

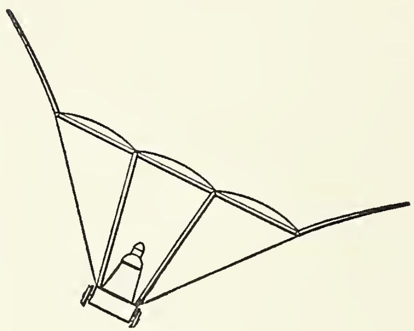


Fig. 11.

When the machine is once perfected, it will not require a railway track to enable it to get the necessary velocity to rise. A short run over a moderately level field will suffice. As far as landing is concerned, the aerial navigator will touch the ground while moving forward, and the machine will be brought to a state of rest by sliding on the ground for a short distance. In this manner very little shock will result, whereas if the machine is stopped in the air and allowed to fall directly to the earth without advancing, the shock, although not strong enough to be dangerous to life or limb, might be sufficient to disarrange or injure the machinery.

VI.

THE COMPARATIVE VALUE OF DIFFERENT MOTORS.

So far I have only discussed the navigation of the air by the use of propellers driven by a steam engine. The engines that I employ are what are known as compound engines, that is, they have a large and a small cylinder. Steam at a very high pressure enters the high pressure cylinder, expands and escapes at a lower pressure into a larger cylinder where it again expands and does more work. A compound engine is more economical in steam than a simple engine, and therefore requires a smaller boiler to develop the same horse-power, so that when we consider the weight of water and fuel for a given time, together with the weight of the boiler and the engine, the complete motor with a compound engine is lighter than a simple engine. However, if only the weight of the engine is to be considered, then the simple engine will develop more power per unit of weight than the compound engine. For instance, if instead of allowing the steam to enter the small cylinder, and the exhaust from this cylinder to enter the large or low-pressure cylinder, which necessitates that the high-pressure piston has to work against a back-pressure equal to the full pressure in the low-pressure cylinder, I should connect both cylinders direct with the live steam and allow both to discharge their exhaust directly into the air. I should then have a pair of simple engines, and instead of developing 363 horse-power, they would develop fully 500 horse-power, or nearly 1 horse-power for every pound of their weight. I mention this fact to show that the engines are exceedingly light, and that when compared with simple engines their power should be computed on the same basis. It will therefore be seen that if we do not take into consideration the steam supply or the amount of fuel and water necessary, the simple steam engine is an exceedingly light motor.

But as before stated, great improvements have recently been made in oil engines. I have thought much on this subject, and am of the opinion that if one had an unlimited supply of money,

a series of experiments could be very profitably conducted with a view of adapting the oil engine for use on flying machines. If we use a steam engine it is necessary to have a boiler, and at the best a boiler is rather a large and heavy object to drive through the air. If we use an oil engine no boiler is necessary and the amount of heat carried over in the cooling water will only be one-seventh part of what is carried over in the exhaust from a steam engine of the same power. Therefore the condenser need only be one-seventh part of the size, and consequently could be made lighter with the tubes placed at a greater distance apart, and thus reduce the amount of power necessary to drive the machine through the air. Moreover, the supply of water necessary will be greatly reduced and a cheaper and heavier oil may be employed which is not so liable to take fire in case of an accident. It is, then, only a question as to whether an oil engine can be made so light as to keep its weight within that of a steam motor; that is, an oil-engine in order to be available for the purpose must be as light, including its water supply, as a complete steam motor which includes not only the engine, but also the boiler, the feed-pumps, the water supply, the burner, the gas generator, and six-sevenths of the condenser. It requires a very perfect steam-engine and boiler, not using a vacuum, to develop a horse-power with a consumption of $1\frac{1}{2}$ pounds of petroleum per hour; but there are many oil engines which develop a horse-power with rather less than one pound of oil per hour. It will therefore be seen that as far as fuel is concerned the oil engine has a decided advantage over the more complicated steam motor. Moreover, with an oil engine the cooling water is not under pressure, so that the waste of water would be much less than with a steam engine, where the pressure is so high as to cause a considerable amount of waste through joints, valves, and numerous stuffing boxes.

The great advances that have been made of late years in electrical science and engineering have led many to believe that almost any knotty scientific question could be solved by the employment of electrical agencies, and a great deal has been

written and said in regard to navigating the air by flying machines driven by electric motors.

Before I commenced my experiments I made inquiries of all the prominent electrical engineering establishments where there was any likelihood of obtaining light and efficient electric motors, and I found that it was impossible to obtain one that would develop a horse-power for any considerable time that would weigh less than 150 lbs. Since that time, notwithstanding that a great deal has appeared in the public prints about the efficiency and lightness of electric motors, I am unable to learn of any concern that is ready to furnish a complete motor, including a primary or secondary battery which would supply the necessary current for two hours at a time, at a weight of less than 150 lbs. per horse-power, and as far as I have been able to ascertain from what I have myself seen, I cannot learn that there are any motors in practical use which do not weigh, including their storage batteries, at least 300 lbs. per horse-power. The last electric motor which I examined was in a boat; it was driven by a primary battery which weighed over 1,000 lbs. to the horse-power. From this I am of the opinion that we can not at present look to electricity with any hope of finding a motor which is suitable for the purpose of aerial navigation.

VII.

CONCLUSION.

My large machine, which was injured in my late experiments, has now been repaired and improved, and is quite ready to be used in any other experiments which I may wish to make on the limited area which I now have at my disposal. The railway track on which my experiments have been made is 1,800 feet long and the land on all sides is thickly studded with large trees. When making experiments about 500 feet of the track is used in getting up the necessary speed and 300 feet is

utilized in bringing the machine again to a state of rest. My clear run is therefore limited to 1,000 feet, and the time which the machine takes to pass over this length of rail is at the most only a few seconds. It will therefore be seen that it is not an easy matter to conduct experiments in a satisfactory manner. In addition to these experiments with a large machine, I am also conducting a series of experiments in a blast of air issuing from a trunk 3 feet square. The air is set in motion by the action of screw propellers driven by a steam engine of 60 horse-power, and I am able to obtain any atmospheric velocity that I require, from 5 to 90 miles an hour. This apparatus is shown in Fig. 6, and is constructed in such a manner that it enables me to mount in this current of air any object that I wish to experiment with. For instance, a bar of wood 3 inches square is mounted in the blast of air so that one of its sides forms a normal plane perpendicular to the direction of the blast. The engine is then run until the air is passing through the trunk at a velocity of 50 miles an hour. The tendency of this bar of wood to travel in the direction of the air may then be accurately determined, and this is considered as unity. A cylinder exactly 3 inches in diameter may then be mounted and tested in the same manner. The cylinder will of course have less tendency to travel with the air than the square bar of wood, and whatever this tendency is, will be the coefficient of a cylinder. I have provided oval, elliptical, and various other shaped objects to be experimented with, and when the experiments are finished I shall know the exact coefficient of all shapes that it may be practical to use in the framework of a flying machine, and also what effect is produced by placing two or more bodies in close proximity to each other.

In addition to these experiments, I am also able with the same air blast to ascertain the efficiency of various forms of aeroplanes, superposed or otherwise, and placed at all angles, the apparatus being provided with a scale beam which not only enables me to measure the drift, but also to accurately weigh the lifting effect. The aeroplane, or grouping of aeroplanes, in

which the drift will go the greatest number of times into the lift will be considered the most satisfactory for the purpose.

Experiments are also being made in the same air blast with a view of ascertaining the condensing and lifting power of various forms of tubes, steam in the condition of exhaust being passed through the tubes while the air is driven between them at any velocity required. The experiments are being made with pure steam and also with steam contaminated with oil, with a view of ascertaining to what extent the efficiency of the condenser is reduced by a film of oil such as may be expected from exhaust steam. These experiments will enable me to ascertain very exactly the weight and the efficiency of atmospheric condensers, the amount that their tubes may be made to lift at various speeds and atmospheric conditions, and will also enable me to select the form which I find most suitable for the purpose.

In navigating a boat, it is only necessary that one should be able to turn it to the right or to the left (port or starboard), but with a flying machine it is not only necessary to steer it to the right or left (horizontally), but also in a vertical direction to prevent it from rearing up forward or pitching, and this, if it is accomplished by hand, will require the constant vigilance of a man at the wheel who can make observations, think, and act instantly. In order to prevent a too rapid up and down deviation of the machine I have constructed it of great length, so that the man at the helm will have more time to think and act. As before stated, however, I am of the opinion that the steering in a vertical direction should be automatically controlled by a gyroscope, and I have made an apparatus which consists of a steam piston acting directly upon the fore and aft rudders, the steam valve being controlled by a gyroscope. As the rudders are moved by the steam, their movement shuts the steam off in exactly the same manner that the moving of a rudder shuts off the steam in the well-known steam-steering apparatus now universally in use on all large steamers.

Now that it is definitely known that it is possible to construct a large machine which is light enough and at the same time

powerful enough to raise its own weight and that of its engineers into the air, the next question which presents itself for solution is to ascertain how to steer and control such a machine when actually free from the earth. When it is considered that the machine is of great size and that it is necessary that it should move through the air at a velocity of at least 35 miles an hour in order to leave the ground, it will be obvious that manœuvring experiments cannot be conducted in a circumscribed place such as I now have. It is therefore necessary for me to obtain new and much larger premises where I shall have a very large and level field at my disposal. It is not an easy matter to obtain a field of this character in England, and it is almost impossible to find a suitable place near London. Moreover, experiments of this character, which are of little value unless conducted on a large scale, are exceedingly expensive, in fact, too expensive to be conducted by private individuals. Nevertheless, as my experiments have shown most conclusively that flying machines are not only possible but practicable, I think I am justified in continuing my experiments until a comparatively perfect flying machine has been evolved. When I have obtained possession of a suitable field, I propose to erect a large building which will contain the machine with all its wings in position. The building which I have at present, notwithstanding that it cost $15,000, is not large enough for the purpose, as the wings all have to be taken off before the machine can be housed.

There are so many points that may be improved that I have determined to build a new machine on a somewhat smaller scale, using about 200 or 250 horse-power. I shall make the engines of a longer stroke in proportion to their diameter so as to get a greater piston speed.[1] I shall construct my screw propellers with 4 long and narrow blades, very sharp and thin, and shall make them large enough so that the pressure on the projected area of the blades will be about 10 lbs. per square foot instead of over 20 lbs. as now. This will greatly reduce the

[1] The present piston speed does not exceed 800 feet per minute. The piston speed of express locomotives is often more than 1,000 feet per minute.

waste of power which is now lost in screw slip. As the present boiler has been found larger than is necessary, my next boiler will be made lighter and smaller, and instead of carrying a pressure of 320 lbs. to the square inch, I shall only carry 275 lbs. But the greatest improvement will be made in the framework of the machine, which will be constructed with a view of enabling everything to be driven through the air with the least possible resistance. The main aeroplane will be the same form as now, but placed at an angle of 1 in 13 instead of 1 in 8, and will be used principally for preventing the machine from accidentally falling to the earth. The principal lifting effect will be derived from a considerable number of relatively narrow aeroplanes placed on each side of the machine and mounted in such a position that the air can pass freely between them. The fore and aft rudders will be the same form as those now employed. The condenser will consist of a large number of small hollow aeroplanes about 2 inches wide, made of very thin and light metal and placed immediately behind the screw-propellers. They will be placed at such an angle as to lift about 1,000 pounds in addition to their weight and the weight of their contents. Instead of mounting my machine as now on 4 wheels, I propose to mount it on 3, the two hind wheels being about 40 feet apart and the forward wheel placed about 60 feet in front of these. I propose to lay down a track of 3 rails, the sleepers being embedded in the ground so as to produce a comparatively level surface. This railway track should be oval or circular in form so that the machine may be heavily weighed to keep it on the track and be run at a high speed. This will enable me to test the furnace draught, the burner, the steam, the boiler, the engines, the propelling effects of the screws, and the efficiency of the condenser while the machine is on the ground.

When all the machinery has been made to run smoothly I shall remove all the weight except that directly over the front wheel, and shall place a device between the wheel and the machine that will indicate the lift on the front end of the machine. I shall then run the machine over the track at a

velocity which will just barely lift the hind wheels off the track, leaving the front wheel on the track. If the rear end of the machine lifts into the air it will change the angle of the planes and the lifting effect will be correspondingly diminished. This will prevent rising too high. Special wheels with a wide face suitable for running on either the rails or the earth will be provided for the purpose, and when I find that I can keep the hind wheels in the air and produce a varying lifting effect above and below the normal weight resting on the front wheel, I shall remove the weight from the forward wheel and attempt free flight by running the machine as near the ground as possible, making the first attempt by running against the wind, and it will only be after I find that I can steer my machine and manage it within a few feet of the earth, ascend and descend again at will, that I shall attempt high flight.

My experiments have certainly demonstrated that a steam engine and boiler may be made which will generate a horse-power for every six pounds of weight, and that the whole motor, including the gas generator, the water supply, the condenser, and the pumps may be all made to come inside of 11 lbs. to the horse-power. They also show that well made screw propellers working in the air are fairly efficient, and that they obtain a sufficient grip upon the air to drive the machine forward at a high velocity; that very large aeroplanes, if well made and placed at a proper angle, will lift as much as 2½ lbs. per square foot at a velocity not greater than 40 miles an hour; also that it is possible for a machine to be made so light and at the same time so powerful that it will lift not only its own weight but a considerable amount besides, with no other energy except that derived from its own engines. Therefore there can be no question but what a flying machine is now possible without the aid of a balloon in any form.

In order to obtain these results it has been necessary for me to make a great number of expensive experiments and to carefully study many of the properties of the air. Both Lord Kelvin and Lord Rayleigh, after witnessing a series of my experiments, expressed themselves as of the opinion that all the

recent experiments will be able to construct a practical flying machine which cannot fail to be a great advantage to mankind.

The numerous and very expensive experiments, conducted on an unprecedented scale, which have made all this possible, and also brought to light new laws relating to the atmosphere, cannot fail to be of the greatest value to mankind, and it is on this basis that I submit the foregoing thesis.

[From Aero. Ann., 1897.]

GLIDING EXPERIMENTS.

By Percy S. Pilcher.

Experimental Department of Hiram S. Maxim.

I made my first trials with a soaring machine in the summer of '95, having constructed the machine during the spring.

I had seen photographs of Lilienthal's apparatus, but I purposely made mine before going to see his so that I should not copy his details. I, however, went to see him fly before I commenced to experiment myself. My first machine had 150 square feet of surface and the wing tips were considerably raised above the body. At first I had a vertical rudder only, but I soon discovered that I could do absolutely nothing without a horizontal rudder. I found that it was quite impossible to control the pitching motions of the machine, and it was not until I had put on the horizontal rudder that I was able to leave the ground at all. This point is very clearly illustrated by experiments with model gliders. It is exceedingly difficult to make a glider with

one surface only which will sail properly, but with two surfaces nothing is easier.

Although a machine in which the wing tips are considerably raised would always tend to right itself when falling, it is almost impossible to use such a machine for practising soaring out of doors, because although the machine is stable enough when the wind is right ahead, if the wind shifts and gets a little on the side it will press the weather wing up and depress the lee one so as to turn the machine over. But when I altered the shape of the wings so that they rose in the centre, but turned down again towards the tips, that is, so that the tips were scarcely higher than the middle of the machine, the machine became comparatively easy to handle, and I was able for a beginner to make some very good jumps. On one occasion when a man towed the machine by a string attached to the front of the machine I spent seventeen seconds in the air, and this is the longest time I have ever been off the ground.

During the summer I made a second machine which was straight transversely, although curved in the fore and aft direction. All the wing surface was considerably raised so that it was just above my head when I was in the machine, but with this machine I could not get along at all. When the weather became too cold I had to stop experimenting, and during the winter I built a new machine, which has 170 square feet of surface and weighs 50 pounds.

During the last summer I had to be very busy about other things, so that I have only had the machine out about ten times and have not been able to choose my days. In this machine I did away with the vertical rudder altogether. For days when there is not much wind the machine is quite manageable as it is, but for squally days I think that a vertical rudder should be added. With this machine I have twice cleared nearly 100 yards, once with a slight side wind and once in a dead calm. Most unfortunately I have never had the machine out when there has been a breeze blowing up the best hill for experimenting, or I should be able to give a much better account of its performances. Once when sailing fast I saw I was going to land in a big bush, so getting back a little in the machine I was able to rise a little and pass quite clear of the bush, although it was quite calm at the time; and I have also been able to steer sideways to a limited extent by moving the weight of my body towards the side to which I wanted the machine to turn. This is the first machine in which I have had any wheels,

which are a great convenience for moving the machine about, and often save the framework from getting broken if one lands clumsily. The wheels are backed by stiff springs which can absorb a considerable blow.

A new machine is being built which will have an oil engine to drive a screw-propeller. With this machine, without the engine, I drop 50 feet in 10 seconds; that is at the rate of 300 feet per minute; taking my weight and the weight of the machine at 220 pounds the work lost per minute will be about 66,000 foot-pounds or 2-horse power. When I have been flown as a kite it seems that about 30 pounds pull will keep me floating at a speed of about 2,200 feet per minute, or 25 miles an hour. $30 \times 2{,}200 = 66{,}000$ foot-pounds = 2-horse power, which comes to just the same thing.

An engine is now being made which will, I hope, exert enough power to overcome the losses arising from friction and slip, and keep the new machine floating horizontally. Of course for the same wing-surface the machine will have to sail faster in order to keep afloat with the extra weight of the engine, and more power than the 2-horse power will therefore have to be used.

About 170 square feet seems to be the best area for a machine of this class for a man of average weight; if it is made larger the machine becomes heavier, and is much more difficult to handle because of its increased size and weight, and if it is smaller its sailing speed becomes unpleasantly great.

Last June I happened to be in Berlin again, and Herr Lilienthal very kindly allowed me to fly off his hill with one of his double surface machines. A light steady breeze was blowing, and after the practice I had had with my own I had no difficulty in handling his machine, but I was very much afraid that with the superposed wings high above the machine, as shown in Lilienthal's latest machine, they would prove very dangerous machines, especially in squally weather.

I hope with the new machine with the engine that I shall be able to obtain results worth reporting in your next ANNUAL, but "we shall see what we shall see."

On Sept. 30, 1899, Mr. Pilcher met with a fatal accident while experimenting near Rugby, England.

[From AERO. ANN., 1895.]

WISE UPON HENSON.

THE machine shown in the accompanying plate was patented by Mr. Henson in England in 1842.

Mr. John Wise, in his book entitled "A System of Aeronautics" (Phila., 1850), writes concerning it as follows:

"The next which is worthy of consideration we find in Henson's idea. Many persons in England were sanguine in the belief that his machine was destined to perfect the art of aerial navigation, and it was seriously contemplated to build one after his model, with which to cross the Atlantic. Indeed, it was well calculated to inspire such a belief in the mere theoretical mind, but to the practical man it at once occurs, What is to keep it from tilting over in losing its balance by a flaw of wind, or any other casualty, and thus tumbling to the ground, admitting that it could raise itself up and move forward?

"The principal feature of the invention is the very great expanse of its sustaining planes, which are larger, in proportion to the weight it has to carry, than those of many birds; but if they had been still greater, they would not have sufficed of themselves to sustain their own weight, to say nothing of their machinery and cargo; surely, though slowly, they would have come to the ground. The machine advances with its front edge a little raised; the effect of which is to present its under surface to the air over which it is passing, the resistance of which, acting on it like a strong wind on the sails of a windmill, prevents the descent of the machine and its burden. The sustaining of the whole, therefore, depends upon the speed at which it is travelling through the air, and the angle at which its under surface impinges on the air in its front; and this is exactly the

principle by which birds are upheld in their flight with but slight motion of their wings, and often with none.

"But, then, this result, after the start, depends entirely on keeping up the speed, and there remains beyond that, the still more formidable difficulty of first obtaining that speed. All former attempts of this kind have failed, because no engine existed that was at once light enough and powerful enough to lift even its own weight through the air with the necessary rapidity. Mr. Henson has removed this difficulty, partly by inventing a steam-engine of extreme lightness and efficiency, and partly by another and very singular device, which requires particular notice. The machine, fully prepared for flight, is started from the top of an inclined plane, in descending which it attains a velocity necessary to sustain it in its further progress. That velocity would be gradually destroyed by the resistance of the air to the forward flight; it is, therefore, the office of the steam-engine and the vanes it actuates simply to repair the loss of velocity; it is made, therefore, only of the power and weight necessary for that small effect. Here, we apprehend, is the chief, but not the only merit and originality of Mr. Henson's invention; and to this happy thought we shall probably be indebted for the first successful attempt to traverse at will another domain of nature."

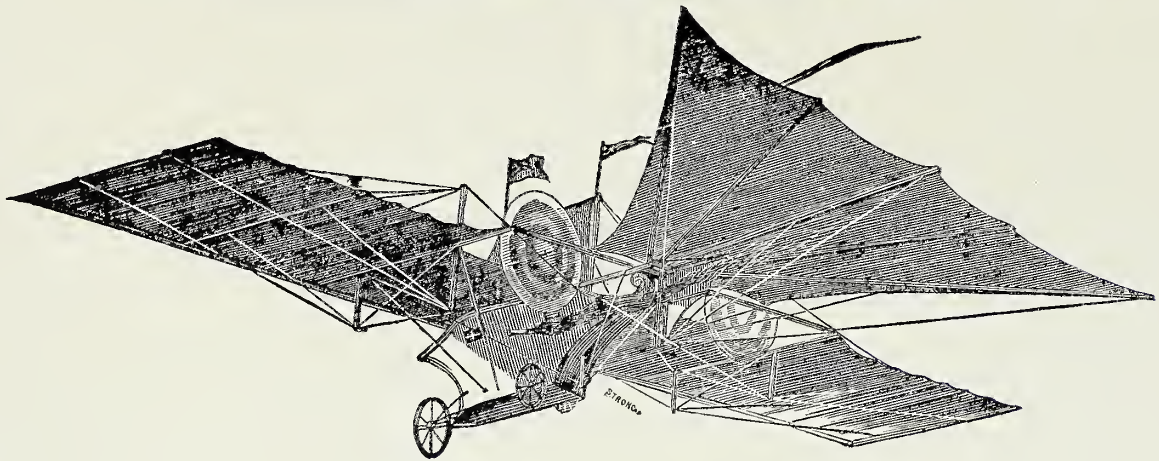
In the "Popular Science Review," 1869, Vol. VIII., p. 1, Mr. F. W. Brearey states that this machine was never constructed.[1]

The account of it is given in this ANNUAL partly because of the interest which attaches to Mr. Henson's plans on account of their date, and partly for the sake of showing what Mr. Wise thought of the combination of an aeroplane with a steam-engine.

Nine years after the publication of his book, Mr. Wise with John La Mountain made one of the most famous balloon voyages on record. They left St. Louis on July 1, 1859; "the States of Illinois and Indiana were passed over in the night and Ohio was reached in the morning. The balloon then passed across Lake Erie into New York, and to Lake Ontario, into

[1] See "Progress in Flying Machines," Chanute, p. 84.

HENSON'S NEW ÆRIAL STEAM CARRIAGE.



From The New York Sun, April 21st, 1843.

Descriptive text may be found in above issue, also in the same paper Feb. 23, 1896.

which it descended, but rose again, and a landing was made in Henderson, Jefferson County, N.Y. The time occupied in making this journey was nineteen hours and fifty minutes, and the distance traversed 1,150 miles, or 826 in an air line."[1]

Twenty years later, in 1879, Mr. Wise again ascended from St. Louis, this time in the "Pathfinder." He was last seen to pass over Illinois in a northeasterly direction, and is supposed to have perished in Lake Michigan. James Glaisher wrote of him: "In America Mr. Wise is *par excellence* the aeronaut; he has made several hundred ascents, and many of them are distinguished for much skill and daring. He also appears to have pursued his profession with more energy and capacity than has any other aeronaut in recent times, and his 'History of Aerostation' shows him to possess much higher scientific attainments than balloonists usually have. In fact, Mr. Wise stands alone in this respect, as nearly all professional aeronauts are destitute of scientific knowledge."

[1] Appleton's Cyclopædia of American Biography, Vol. III., p. 602. See also Vol. VI., p. 581.

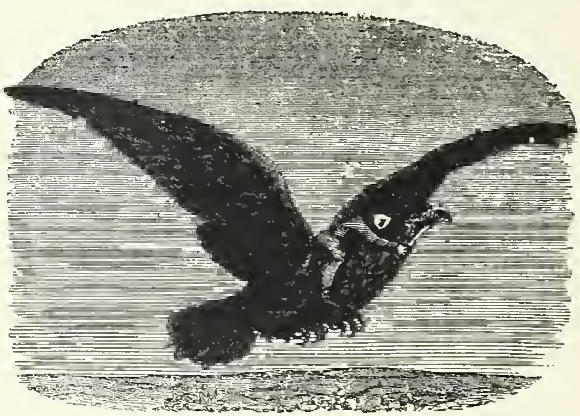
A TABLE OF WIND VELOCITIES,

FOR THE YEAR 1892.

Compiled from the Report of the Chief of the Weather Bureau, 1891-92.

MAXIMUM VELOCITIES ARE FOR A FIVE-MINUTE PERIOD. A WIND VELOCITY OF 40 MILES PER HOUR IS CONSIDERED A GALE.

	Average for the year. Miles per hour.	Maximum monthly average. Miles per hour.	Minimum monthly average. Miles per hour.	Maximum velocity.	Number of days with gales.
Boston, Mass.	12.0	15.9 in March.	9.6 in July.	48	8
Buffalo, N.Y.	10.9	13.7 in December.	8.4 in August.	55	26
Chattanooga, Tenn.	5.1	7.5 in April.	3.4 in September.	35	0
Chicago, Ill.	16.8	22.2 in April.	13.2 in June.	72	59
Cleveland, O.	11.1	15.6 in November.	8.2 in March.	64	16
Denver, Col.	7.4	9.1 in April.	5.3 in February.	48	3
New Orleans, La.	8.8	12.0 in April.	6.0 in August.	50	5
New York, N.Y.	10.8	14.6 in March.	6.9 in August.	49	6
Pittsburgh, Pa.	6.5	8.4 in November.	4.6 in July.	38	0
Portland, Me.	8.4	10.9 in March.	7.2 in August.	45	4
Portland, Ore.	6.0	9.2 in November.	4.6 in January.	41	2
St. Louis, Mo.	11.0	13.4 in January.	8.1 in August.	48	13
San Francisco, Cal.	8.7	12.0 in July.	4.5 in January.	60	6
Savannah, Ga.	7.8	9.0 in April.	6.2 in August.	32	0



[From AERO. ANN., 1897.]

STORY OF EXPERIMENTS IN MECHANICAL FLIGHT.

BY SAMUEL PIERPONT LANGLEY.

THE Editor of "The Annual" has asked me to give matter of a somewhat personal nature for a narrative account of my work in aerodromics.

The subject of flight interested me as long ago as I can remember anything, but it was a communication from Mr. Lancaster, read at the Buffalo meeting of the American Association for the Advancement of Science, in 1886, which aroused my then dormant attention to the subject. What he said contained some remarkable but apparently mainly veracious observations on the soaring bird, and some more or less paradoxical assertions, which caused his communication to be treated with less consideration than it might otherwise have deserved. Among these latter was a statement that a model, somewhat resembling a soaring bird, wholly inert, and without any internal power, could, nevertheless, under some circumstances advance against the wind without falling; which seemed to me then, as it did to members of the Association, an utter impossibility, but which I have since seen reason to believe is, within limited conditions, theoretically possible.

I was then engaged in the study of astro-physics at the Observatory in Allegheny, Pennsylvania. The subject of mechanical flight could not be said at that time to possess any literature, unless it were the publications of the French and English aeronautical societies, but in these, as in everything then accessible, fact had not yet always been discriminated from fancy. Outside of these, almost everything was even less trustworthy; but though after I had experimentally demonstrated

certain facts, anticipations of them were found by others on historical research, and though we can now distinguish in retrospective examination what would have been useful to the investigator if he had known it to be true, there was no test of the kind to apply at the time. I went to work, then, to find out for myself, and in my own way, what amount of mechanical power was requisite to sustain a given weight in the air, and make it advance at a given speed, for this seemed to be an inquiry which must necessarily precede any attempt at mechanical flight, which was the very remote aim of my efforts.

The work was commenced in the beginning of 1887 by the construction, at Allegheny, of a turn-table of exceptional size, driven by a steam-engine, and this was used during three years in making the "Experiments in Aerodynamics," which were published by the Smithsonian Institution, under that title, in 1891. Nearly all the conclusions reached were the result of direct experiment in an investigation which aimed to take nothing on trust. Few of them were then familiar, though they have since become so, and in this respect knowledge has advanced so rapidly that statements which were treated as paradoxical on my first enunciation of them are now admitted truisms.

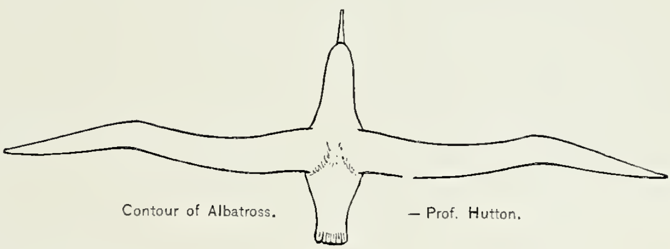
It has taken me, indeed, but a few years to pass through the period when the observer hears that his alleged observation was a mistake; the period when he is told that if it were true, it would be useless; and the period when he is told that it is undoubtedly true, but that it has always been known.

May I quote from the introduction to this book what was said in 1891?

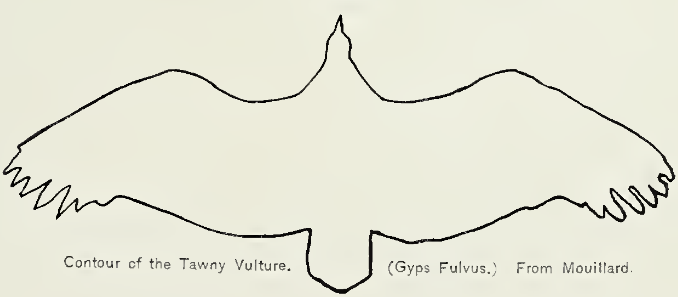
"I have now been engaged since the beginning of the year 1887 in experiments on an extended scale for determining the possibilities of, and the conditions for, transporting in the air a body whose specific gravity is greater than that of the air, and I desire to repeat my conviction that the obstacles in its way are not such as have been thought; that they lie more in such apparently secondary difficulties as those of guiding the body so that it may move in the direction desired, and ascend or

LANGLEY'S AERODROME IN FLIGHT.

May 6, 1896.



Contour of Albatross. — Prof. Hutton.



Contour of the Tawny Vulture. (Gyps Fulvus.) From Mouillard.

descend with safety, than in what may appear to be the primary difficulties due to the nature of the air itself," and, I added, that in this field of research I thought that we were, at that time (only six years since), "in a relatively less advanced condition than the study of steam was before the time of Newcomen." It was also stated that the most important inference from those experiments as a whole was that mechanical flight was possible with engines we could then build, as one-horse power rightly applied could sustain over 200 pounds in the air at a horizontal velocity of somewhat over 60 feet a second.

As this statement has been misconstrued, let me point out that it refers to surfaces, used without guys, or other adjuncts, which would create friction; that the horse-power in question is that actually expended in the thrust, and that it is predicated only on a rigorously horizontal flight. This implies a large deduction from the power in the actual machine, where the brake horse-power of the engine, after a requisite allowance for loss in transmission to the propellers, and for their slip on the air, will probably be reduced to from one-half to one-quarter of its nominal amount; where there is great friction from the enforced use of guys and other adjuncts; but above all where there is no way to insure absolutely horizonal flight in free air. All these things allowed for, however, since it seemed to me possible to provide an engine which should give a horse-power for something like 10 pounds of weight, there was still enough to justify the statement that we possessed in the steam-engine, as then constructed, or in other heat engines, more than the indispensable power, though it was added that this was not asserting that a system of supporting surfaces could be securely guided through the air or safely brought to the ground, and that these and like considerations were of quite another order, and belonged to some inchoate art which I might provisionally call *aerodromics*.

These important conclusions were reached before the actual publication of the volume, and a little later others on the nature of the movements of air, which were published under the title of "The Internal Work of the Wind" (Smithsonian Contribu-

tions to Knowledge, Volume XXVII., 1893, No. 884). The latter were founded on experiments independent of the former, and which led to certain theoretical conclusions unverified in practice. Among the most striking and perhaps paradoxical of these, was that a suitably disposed free body might under certain conditions be sustained in an ordinary wind, and even advance against it without the expenditure of any energy from within.

The first stage of the investigation was now over, so far as that I had satisfied myself that mechanical flight was possible with the power we could hope to command, if only the art of directing that power could be acquired.

The second stage (that of the acquisition of this art) I now decided to take up. It may not be out of place to recall that at this time, only six years ago, a great many scientific men treated the whole subject with entire indifference as unworthy of attention or as outside of legitimate research, the proper field for the charlatan, and one on which it was scarcely prudent for a man with a reputation to lose, to enter.

The record of my attempts to acquire the art of flight may commence with the year 1889, when I procured a stuffed frigate bird, a California condor, and an albatross, and attempted to move them upon the whirling table at Allegheny. The experiments were very imperfect and the records are unfortunately lost, but the important conclusion to which they led was that a stuffed bird could not be made to soar except at speeds which were unquestionably very much greater than what served to sustain the living one, and the earliest experiments and all subsequent ones with actually flying models have shown that thus far we cannot carry nearly the weights which Nature does to a given sustaining surface, without a power much greater than she employs. At the time these experiments were begun, Penaud's ingenious but toy-like model was the only thing which could sustain itself in the air for even a few seconds, and calculations founded upon its performance sustained the conclusion that the amount of power required in actual free flight was far greater than that demanded by the

theoretical enunciation. In order to learn under what conditions the aerodrome should be balanced for horizontal flight, I constructed over 30 modifications of the rubber-driven model, and spent many months in endeavoring from these to ascertain the laws of "balancing"; that is, of stability leading to horizontal flight. Most of these models had two propellers, and it was extremely difficult to build them light and strong enough. Some of them had superposed wings; some of them curved and some plane wings; in some the propellers were side by side, in others one propeller was at the front and the other at the rear, and so every variety of treatment was employed, but all were at first too heavy, and only those flew successfully which had from 3 to 4 feet of sustaining surface to a pound of weight, a proportion which is far greater than Nature employs in the soaring bird, where in some cases less than half a foot of sustaining surface is used to a pound. It had been shown in the "Experiments in Aerodynamics" that the centre of pressure on an inclined plane advancing was not at the centre of figure, but much in front of it, and this knowledge was at first nearly all I possessed in balancing these early aerodromes. Even in the beginning, also, I met remarkable difficulty in throwing them into the air, and devised numerous forms of launching apparatus which were all failures, and it was necessary to keep the construction on so small a scale that they could be cast from the hand.

The earliest actual flights with these were extremely irregular and brief, lasting only from three to four seconds. They were made at Allegheny in March, 1891, but these and all subsequent ones were so erratic and so short that it was possible to learn very little from them. Penaud states that he once obtained a flight of 13 seconds. I never got as much as this, but ordinarily little more than half as much, and came to the conclusion that in order to learn the art of mechanical flight it was necessary to have a model which would keep in the air for at any rate a longer period than these, and move more steadily. Rubber twisted in the way that Penaud used it, will practically give about 300 foot-pounds to a pound of weight, and at least as much must be

allowed for the weight of the frame on which the rubber is strained. Twenty pounds of rubber and frame, then, would give 3,000 foot-pounds, or one-horse power for less than six seconds. A steam-engine, having apparatus for condensing its steam, weighing in all 10 pounds and carrying 10 pounds of fuel, would possess in this fuel, supposing that but one-tenth of its theoretical capacity is utilized, many thousand times the power of an equal weight of rubber, or at least one-horse power for some hours. Provided the steam could be condensed and the water re-used, then, the advantage of the steam over the spring motor was enormous, even in a model constructed only for the purpose of study. But the construction of a steam-driven aerodrome was too formidable a task to be undertaken lightly, and I examined the capacities of condensed air, carbonic acid gas, of various applications of electricity, whether in the primary or storage battery, of hot-water engines, of inertia motors, of the gas engine, and of still other material. The gas engine promised best of all in theory, but it was not yet developed in a suitable form. The steam-engine, as being an apparently familiar construction, promised best in practice, but in taking it up, I, to my cost, learned that in the special application to be made of it, little was really familiar and everything had to be learned by experiment. I had myself no previous knowledge of steam engineering, nor any assistants other than the very capable workmen employed. I well remember my difficulties over the first aerodrome (No. 0), when everything, not only the engine, but the boilers which were to supply it, the furnaces which were to heat it, the propellers which were to advance it, the hull which was to hold all these, — were all things to be originated, in a construction which, as far as I knew, had never yet been undertaken by any one.

It was necessary to make a beginning, however, and a compound engine was planned which, when completed, weighed about 4 pounds, and which could develop rather over a horse-power with 60 pounds of steam, which it was expected could be furnished by a series of tubular boilers arranged in "bee-hive" form, and the whole was to be contained in a hull about 5 feet in

length and 10 inches in diameter. This hull was, as in the construction of a ship, to carry all adjuncts. In front of it projected a steel rod, or bowsprit, about its own length, and one still longer behind. The engines rotated two propellers, each about 30 inches in diameter, which were on the end of long shafts disposed at an acute angle to each other and actuated by a single gear driven from the engine. A single pair of large wings contained about 50 square feet, and a smaller one in the rear about half as much, or in all some 75 feet, of sustaining surface, for a weight which it was expected would not exceed 25 pounds.

Although this aerodrome was in every way a disappointment, its failure taught a great many useful lessons. It had been built on the large scale described, with very little knowledge of how it was to be launched into the air, but the construction developed the fact that it was not likely to be launched at all, since there was a constant gain in weight over the estimate at each step, and when the boilers were completed, it was found that they gave less than one-half the necessary steam, owing chiefly to the inability to keep up a proper fire. The wings yielded so as to be entirely deformed under a slight pressure of the air, and it was impossible to make them stronger without making them heavier, where the weight was already prohibitory. The engines could not transmit even what feeble power they furnished, without dangerous tremor in the long shafts, and there were other difficulties. When the whole approached completion, it was found to weigh nearer 50 pounds than 25, to develop only about one-half the estimated horsepower at the brake, to be radically weak in construction, owing to the yielding of the hull, and to be, in short, clearly a hopeless case.

The first steam-driven aerodrome had, then, proved a failure, and I reverted during the remainder of the year to simpler plans, among them one of an elementary gasolene engine.

I may mention that I was favored with an invitation from Mr. Maxim to see his great flying-machine at Bexley, in Kent, where I was greatly impressed with the engineering skill shown in its construction, but I found the general design in-

compatible with the conclusions that I had reached by experiments with small models, particularly as to what seemed to me advisable in the carrying of the centre of gravity as high as was possible with safety.

In 1892 another aerodrome (No. 1), which was to be used with carbonic acid gas, or with compressed air, was commenced. The weight of this aerodrome was a little over 4½ pounds, and the area of the supporting surfaces 6½ square feet. The engines developed but a small fraction of a horse-power, and they were able to give a dead lift of only about one-tenth of the weight of the aerodrome, giving relatively less power to weight than that obtained in the large aerodrome already condemned.

Toward the close of this year was taken up the more careful study of the position of the centre of gravity with reference to the line of thrust from the propellers, and to the centre of pressure. The centre of gravity was carried as high as was consistent with safety, the propellers being placed so high, with reference to the supporting wings, that the intake of air was partly from above and partly from below these latter. The lifting power (*i.e.*, the dead-lift) of the aerodromes was determined in the shop by a very useful contrivance which I have called the "pendulum," which consists of a large pendulum which rests on knife edges, but is prolonged above the points of support, and counterbalanced so as to present a condition of indifferent equilibrium. Near the lower end of this pendulum the aerodrome is suspended, and when power is applied to it, the reaction of the propellers lifts the pendulum through a certain angle. If the line of thrust passes through the centre of gravity, it will be seen that the sine of this angle will be the fraction of the weight lifted, and thus the dead-lift power of the engines becomes known. Another aerodrome was built, but both, however constructed, were shown by this pendulum test to have insufficient power, and the year closed with disappointment.

Aerodrome No. 3 was of stronger and better construction, and the propellers, which before this had been mounted on shafts inclined to each other in a V-like form, were replaced by par-

allel ones. Boilers of the Serpolet type (that is, composed of tubes of nearly capillary section) were experimented with at great cost of labor and no results; and they were replaced with coil boilers. For these I introduced, in April, 1893, a modification of the ælopile blast, which enormously increased the heat-giving power of the fuel (which was then still alcohol), and with this blast for the first time the boilers began to give steam enough for the engines. It had been very difficult to introduce force pumps which would work effectively on the small scale involved, and after many attempts to dispense with their use by other devices, the acquisition of a sufficiently strong pump was found to be necessary in spite of its weight, but was only secured after long experiment. It may be added that all the aerodromes from the very nature of their construction were wasteful of heat, the industrial efficiency little exceeding half of one per cent., or from one-tenth to one-twentieth that of a stationary engine constructed under favorable conditions. This last aerodrome lifted nearly 30 per cent. of its weight upon the pendulum, which implied that it could lift much more than its weight when running on a horizontal track, and its engines were capable of running its 50-centimetre propellers at something over 700 turns per minute. There was, however, so much that was unsatisfactory about it, that it was deemed best to proceed to another construction before an actual trial was made in the field, and a new aerodrome, designated as No. 4, was begun. This last was an attempt, guided by the weary experience of preceding failures, to construct one whose engines should run at a much higher pressure than heretofore, and be much more economical in weight. The experiments with the Serpolet boilers having been discontinued, the boiler was made with a continuous helix of copper tubing, which as first employed was about three millimetres internal diameter; and it may be here observed that a great deal of time was subsequently lost in attempts to construct a more advantageous form of boiler for the actual purposes than this simple one, which with a larger coil tube eventually proved to be the best; so that later constructions have gone back to this earlier type. A great deal of time was lost in these experi-

ments from my own unfamiliarity with steam engineering, but it may also be said that there was little help either from books or from counsel, for everything was here *sui generis*, and had to be worked out from the beginning. In the construction which had been reached by the middle of the third year of experiment, and which has not been greatly differed from since, the boiler was composed of a coil of copper in the shape of a hollow helix, through the centre of which the blast from the ælopile was driven, the steam and water passing into a vessel I called the "separator," whence the steam was led into the engines at a pressure of from 70 to 100 pounds (a pressure which has since been considerably exceeded).

From the very commencement of this long investigation the great difficulty was in keeping down the weight, for any of the aerodromes could probably have flown had they been built light enough, and in every case before the construction was completed the weight had so increased beyond the estimate, that the aerodrome was too heavy to fly, and nothing but the most persistent resolution kept me in continuing attempts to reduce it after further reduction seemed impossible. Toward the close of the year (1893) I had, however, finally obtained an aerodrome with mechanical power, as it seemed to me, to fly, and I procured, after much thought as to where this flight should take place, a small house-boat, to be moored somewhere in the Potomac; but the vicinity of Washington was out of the question, and no desirable place was found nearer than thirty miles below the city. It was because it was known that the aerodrome might have to be set off in the face of a wind, which might blow in any direction, and because it evidently was at first desirable that it should light in the water rather than on the land, that the house-boat was selected as the place for the launch. The aerodrome (No. 4) weighed between 9 and 10 pounds, and lifted 40 per cent. of this on the pendulum with 60 pounds of steam pressure, a much more considerable amount than was theoretically necessary for horizontal flight. And now the construction of a launching apparatus, dismissed for some years, was resumed. Nearly every form seemed to have been experi-

mented with unsuccessfully in the smaller aerodromes. Most of the difficulties were connected with the fact that it is necessary for an aerodrome, as it is for a soaring bird, to have a certain considerable initial velocity before it can advantageously use its own mechanism for flight, and the difficulties of imparting this initial velocity with safety are surprisingly great, and in the open air are beyond all anticipation.

Here, then, commences another long story of delay and disappointment in these efforts to obtain a successful launch. To convey to the reader an idea of its difficulties, a few extracts from the diary of the period are given. (It will be remembered that each attempt involved a journey of thirty miles each way.)

Nov. 18, 1893. Having gone down to the house-boat, preparatory to the first launch, in which the aerodrome was to be cast from a springing piece beneath, it was found impossible to hold it in place on this before launching, without its being prematurely torn from its support, although there was no wind except a moderate breeze; and the party returned after a day's fruitless effort.

Two days later a relative calm occurred in the afternoon of a second visit, when the aerodrome was mounted again, but, though the wind was almost imperceptible, it was sufficient to wrench it about so that at first nothing could be done, and when steam was gotten up, the burning alcohol blew about so as to seriously injure the inflammable parts. Finally, the engines being under full steam, the launch was attempted, but, owing to the difficulties alluded to and to a failure in the construction of the launching piece, the aerodrome was thrown down upon the boat, fortunately with little damage.

Whatever form of launch was used it became evident at this time that the aerodrome must at any rate be firmly held, up to the very instant of release, and a device was arranged for clamping it to the launching apparatus.

On November 24th another attempt was made to launch, which was rendered impossible by a very moderate wind indeed.

On November 27th a new apparatus was arranged to merely drop the aerodrome over the water, with the hope that it would

get up sufficient speed before reaching the surface to soar, but it was found that a very gentle intermittent breeze (probably not more than three or four miles an hour) was sufficient to make it impossible even to prepare to *drop* the aerodrome toward the water with safety.

It is difficult to give an idea in few words of the nature of the trouble, but unless one stands with the machine in the open air he can form no conception of what the difficulties are which are peculiar to practice in the open, and which do not present themselves to the constructor in the shop, nor probably to the mind of the reader.

December 1st, another failure; December 7th, another; December 11th, another; December 20th, another; December 21st, another. These do not all involve a separate journey, but five separate trips were made of a round distance of 60 miles each before the close of the season. It may be remembered that these attempts were in a site far from the conveniences of the workshop, and under circumstances which took up a great deal of time, for some hours were spent on mounting the aerodrome on each occasion, and the year closed without a single cast of it into the air. It was not known how it would have behaved there, for there had not been a launch, even, in nine trials, each one representing an amount of trouble and difficulty which this narrative gives no adequate idea of.

I pass over a long period of subsequent baffled effort, with the statement that numerous devices for launching were tried in vain, and that nearly a year passed before one was effected.

Six trips and trials were made in the first six months of 1894, without securing a launch. On the 24th of October a new launching piece was tried for the first time, which embodied all the requisites whose necessity was taught by previous experience, and, saving occasional accidents, the launching was from this time forward accomplished with comparatively little difficulty.

The aerodromes were now for the first time put fairly in the air, and a new class of difficulties arose, due to a cause which was at first obscure, — for two successive launches of the same

aerodrome, under conditions as near alike as possible, would be followed by entirely different results. For example, in the first case it might be found rushing, not falling, forward and downward into the water under the impulse of its own engines; in the second case, with every condition from observation apparently the same, it might be found soaring upward until its wings made an angle of 60 degrees with the horizon, and, unable to sustain itself at such a slope, sliding backward into the water.

After much embarrassment the trouble was discovered to be due to the fact that the wings, though originally set at precisely the same position and same angle in the two cases, were irregularly deflected by the upward pressure of the air, so that they no longer had the form which they appeared to possess but a moment before they were upborne by it, and so that a very minute difference, too small to be certainly noted, exaggerated by this pressure, might cause the wind of advance to strike either below or above the wing and to produce the salient difference alluded to. When this was noticed all aerodromes were inverted, and sand was dredged uniformly over the wings until its weight represented that of the machine. The flexure of the wings under these circumstances must be nearly that in free air, and it was found to distort them beyond all anticipation. Here commences another series of trials in which the wings were strengthened in various ways, but in none of which, without incurring a prohibitive weight, was it possible to make them strong enough. Various methods of guying them were tried, and they were rebuilt on different designs,—a slow and expensive process. Finally, it may be said, in anticipation (and largely through the skill of Mr. Reed, the foreman of the work), the wings were rendered strong enough without excessive weight, but a year or more passed in these and other experiments.

In the latter part of 1894 two steel aerodromes had already been built which sustained from 40 to 50 per cent. of their dead-lift weight on the pendulum, and each of which was apparently supplied with much more than sufficient power for horizontal flight (the engine and all the moving parts furnish-

ing over one-horse power at the brake weighed in one of these but 26 ounces); but it may be remarked that the boilers and engines in lifting this per cent. of the weight did so only at the best performance in the shop, and that nothing like this could be counted upon for regular performance in the open. Every experiment with the launch, when the aerodrome descended into the water, not gently, but impelled by the misdirected power of its own engines, resulted at this stage in severe strains and local injury, so that repairing, which was almost rebuilding, constantly went on, — a hard but necessary condition attendant on the necessity of trial in the free air. It was gradually found that it was indispensable to make the frame stronger than had hitherto been done, though the absolute limit of strength consistent with weight seemed to have been already reached, and the year 1895 was chiefly devoted to the labor on the wings and what seemed at first the hopeless task of improving the construction so that it might be stronger without additional weight, when every gramme of weight had already been scrupulously economized. With this went on attempts to carry the effective power of the burners, boilers, and engines further, and modification of the internal arrangement and a general disposition of the parts such that the wings could be placed further forward or backward at pleasure, to more readily meet the conditions necessary for bringing the centre of gravity under the centre of pressure. So little had even now been learned about the system of balancing in the open air that at this late day recourse was again had to rubber models, of a different character, however, from those previously used, for in the latter the rubber was strained, not twisted. These experiments took up an inordinate time, though the flight obtained from the models thus made was somewhat longer and much steadier than that obtained with the Penaud form, and from them a good deal of valuable information was gained as to the number and position of the wings, and as to the effectiveness of different forms and dispositions of them. By the middle of the year a launch took place with a brief flight, where the aerodrome shot down into the water after a little over 50 yards. It was

immediately followed by one in which the same aerodrome rose at a considerable incline and fell backward, with scarcely any advance after sustaining itself rather less than ten seconds, and these and subsequent attempts showed that the problem of disposing of the wings so that they would not yield, and of obtaining a proper " balance," was not yet solved.

Briefly it may be said that the year 1895 gave small results for the labor with which it was filled, and that at its close the outlook for further substantial improvement seemed to be almost hopeless, but it was at this time that final success was drawing near. Shortly after its close I became convinced that substantial rigidity had been secured for the wings; that the frame had been made stronger without prohibitive weight, and that a degree of accuracy in the balance had been obtained which had not been hoped for. Still there had been such a long succession of disasters and accidents in the launching that hope was low when success finally came.

I have not spoken here of the aid which I received from others, and particularly from Doctor Carl Barus and Mr. J. E. Watkins, who have been at different times associated with me in the work. Mr. R. L. Reed's mechanical skill has helped me everywhere, and the lightness and efficiency of the engines are in a large part due to Mr. L. C. Maltby.

[From Aero. Ann., 1897.]

THE AERODROMES IN FLIGHT.

THE successful flights of Dr. Langley's aerodrome were witnessed by Dr. Bell and described by him as follows: [1]

Through the courtesy of Dr. S. P. Langley, Secretary of the Smithsonian Institution, I have had, on various occasions, the privilege of witnessing his experiments with aerodromes, and especially the remarkable success attained by him in experiments made upon the Potomac river on Wednesday, May 6, 1896, which led me to urge him to make public some of these results.

I had the pleasure of witnessing the successful flight of some of these aerodromes more than a year ago, but Dr. Langley's reluctance to make the results public at that time prevented me from asking him, as I have done since, to let me give an account of what I saw.

On the date named two ascensions were made by the aerodrome, or so-called "flying-machine," which I will not describe here further than to say that it appeared to me to be built almost entirely of metal, and driven by a steam-engine which I have understood was carrying fuel and a water supply for a very brief period, and which was of extraordinary lightness.

The absolute weight of the aerodrome, including that of the engine and all appurtenances, was, as I was told, about 25 pounds, and the distance from tip to tip of the supporting surfaces was, as I observed, about 12 or 14 feet. The method of propulsion was by aerial screw-propellers, and there was no gas or other aid for lifting it in the air except its own internal energy.

On the occasion referred to, the aerodrome, at a given signal, started from a platform about 20 feet above the water, and rose at first directly in the face of the wind, moving at all times with remarkable steadiness, and subsequently swinging around in large curves of, perhaps, a hundred yards in diameter, and continually ascending until its steam was exhausted, when, at a lapse of about a minute and a half, and at a height which I

[1] "Nature," London, May 28, 1896.

judged to be between 80 and 100 feet in the air, the wheels ceased turning, and the machine, deprived of the aid of its propellers, to my surprise did not fall, but settled down so softly and gently that it touched the water without the least shock, and was in fact immediately ready for another trial.

In the second trial, which followed directly, it repeated in nearly every respect the actions of the first, except that the direction of its course was different. It ascended again in the face of the wind, afterwards moving steadily and continually in large curves accompanied with a rising motion and a lateral advance. Its motion was, in fact, so steady, that I think a glass of water on its surface would have remained unspilled. When the steam gave out again, it repeated for a second time the experience of the first trial when the steam had ceased, and settled gently and easily down. What height it reached at this trial I cannot say, as I was not so favorably placed as in the first; but I had occasion to notice that this time its course took it over a wooded promontory, and I was relieved of some apprehension in seeing that it was already so high as to pass the tree-tops by 20 or 30 feet. It reached the water 1 minute and 31 seconds from the time it started, at a measured distance of over 900 feet from the point at which it rose.

This, however, was by no means the length of its flight. I estimated from the diameter of the curve described, from the number of turns of the propellers as given by the automatic counter, after due allowance for slip, and from other measures, that the actual length of flight on each occasion was slightly over 3,000 feet. It is at least safe to say that each exceeded half an English mile.

From the time and distance it will be noticed that the velocity was between 20 and 25 miles an hour, in a course which was taking it constantly "up hill." I may add that on a previous occasion I have seen a far higher velocity attained by the same aerodrome when its course was horizontal.

I have no desire to enter into detail further than I have done, but I cannot but add that it seems to me that no one who was present on this interesting occasion could have failed to recognize that the practicability of mechanical flight had been demonstrated.

ALEXANDER GRAHAM BELL.

Not long after the May experiments Dr. Langley went abroad for needed rest and recreation, and in the autumn, after his

return, further experiments were tried. On the 28th of November a flight was made which was more than three-quarters of a mile in length, the time occupied being precisely one minute and three-quarters. Mr. Frank G. Carpenter was a fortunate witness of this, the longest flight ever made, and with Dr. Langley's approval he wrote a detailed account of it for the "Washington Star" of Dec. 12, 1896. His article is interesting from beginning to end.

1910. *Note.*—The active interest in the designing and flying of model machines is fortunately increasing steadily. The time is probably far distant when experiments with models will cease to be instructive.

Those who have made considerable advance in the designing of models may find it to their advantage to construct their models upon a scale of one-half or one-quarter that of a one-man machine. This will facilitate computations. Especial attention is called to the subject of elasticity in the rear edges of sustaining surfaces. — ED.

[From AERO. ANN., 1897.]

THE SCIENTIFIC VALUE OF FLYING MODELS.

BY THE EDITOR.

THE ultimate object of aeronautical study and experiment is, of course, to hasten the time when it shall be possible to construct a *practical* flying machine.

There are some experimenters who think that the day of the great achievement will come sooner if in the immediate future we give the most of our time and thought to the development of the motorless air-sailer. Others think that more rapid progress will be made through the development of the self-propelled aerodrome.

It is quite needless to attempt at this time to say who is right; time will show us all that. Moreover, as stated in the introductory note, whichever branch of work is seriously undertaken by an individual, he may be sure that while working upon his own specialty he is helping those engaged in the others toward their common goal.

The supreme importance which attaches to the flying model comes from the fact that experiments with it may be made to lessen the number of risks of human life and limb. We have now reached the stage of experiment where it is necessary to use all possible persuasion to keep reasonably near *terra firma* those persons who have nothing but the courage of ignorance

to equip them for ventures in the air. A part of the glory of the work of '96 at Camp Chanute comes from the fact that no one of the experimenters was injured, all being under the control of an accomplished scientist, firm and clear-headed. If the lamented Lilienthal, with his great knowledge of engineering, his long experience, and his superb self-control, could come to his untimely end, is Fate likely to be kind to the novice?

Remembering that Lilienthal said, "It is not every man's business to launch himself into space," and knowing that there are some men who are so situated that experiments with models are the only ones which they can undertake, let us consider the possible value of the results of such experiments.

We can readily see that many models otherwise excellent will have limitations to their usefulness because of the laws governing the strength of materials. In designing a model it is advisable to keep in mind, so far as possible, the probability of the retention of its good qualities in case its enlarged counterpart is constructed. We know that the elements of strength contained in the model, which will also appear in a full-sized machine, are those which have come from the engineering skill shown in the structure, and that these elements must be so far in excess of the actual needs of the model that they will offset the great loss in the proportional strength of materials which occurs when the size of machines is increased.

I once knew of an imposing piece of experimental apparatus, having several hundred square feet of surface, which was withered by the wind because the designer had forgotten the simple point just mentioned.

It is not necessary to immediately settle the question as to how far the performance of a model is a *demonstration* of what can be done with its enlarged counterpart; it is enough for the present to know that experiments with models can throw much light upon several subjects that are now imperfectly understood. The following are some of these:

1. Automatic devices for preserving equilibrium.
2. Disposition of surfaces.
3. Placing of screws.

4. Curves of surfaces.
5. Relation of weight to area.
6. Relation of power to weight.
7. Effects of elasticity in sustaining surfaces.

Any one of these subjects is enough to occupy an experimenter for a long time.

In regard to the first subject it will be noticed that the contributors to THE ANNUAL have given no detailed descriptions of the automatic devices which they have tried. This is because of the conservatism which leads every rational experimenter to withhold details from the public until his own tests have satisfied him that the proper time has come to make an announcement.

Mr. Chanute in his book[1] describes many attempts which have been made to secure automatic equilibrium, and it goes without saying that no one will begin any kind of aeronautical experiment until he has given to that book the most thorough study. It may here be said that rolling balls, shifting mercury ballast, and pendulum devices to move rudders have been tried, but none of these have so far given satisfactory results.

If there is one man whose name is mentioned oftener than that of any other in connection with the subject of automatic equilibrium it is that of Alphonse Pénaud,[2] whose flying models attracted much attention twenty years ago and recently have attracted still more.

In 1874 Mr. T. J. Bennett, of Oxford, brought Pénaud's automatic rudder to the notice of the Aeronautical Society of Great Britain, in the following words:

> But all the above models flew by accident, there being no special means provided for maintaining the equilibrium fore and aft. This problem M. Pénaud has solved by means of his automatic rudder. . . .
>
> At last the idea occurred to him of placing a small horizontal rudder behind the sustaining planes, and inclined at a small angle to them. It succeeded perfectly. Its mode of action is as follows:
>
> The centre of gravity of the machine is placed a little in front of the centre of pressure of the aeroplane, so that it tends to make the model descend an

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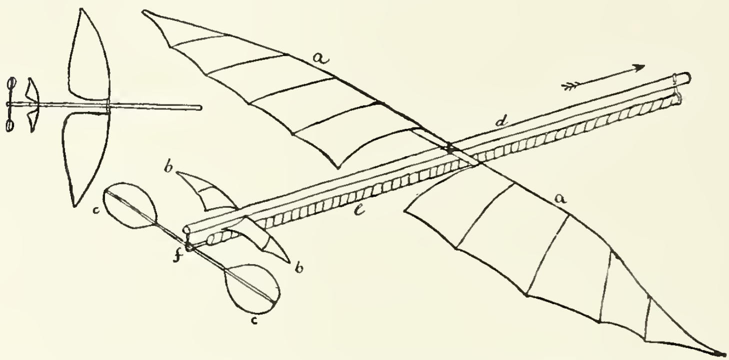
[1] "Progress in Flying Machines." Published by M. N. Forney, N.Y., 1894.

[2] A Frenchman, now of honored memory, who died in sorrow and disappointment in 1880, before reaching the age of thirty years. See "Progress in Flying Machines," pp. 117–122.

incline; but in so doing it lessens the angle of inclination of the aeroplane, and the speed is increased. At the same time the angle of the horizontal rudder is increased, and the pressure of air on its upper surface causes it to descend; but as the machine tends to turn round its centre of gravity, the front part is raised and brought back to the horizontal position. If owing to the momentum gained during the descent the machine still tends upwards, the angle of the plane is increased and the speed decreased. The angle of the rudder from the horizontal being reduced, it no longer receives the pressure of the air on its superior surface, the weight in front reasserts its power, and the machine descends. Thus by the alternate action of the weight in front and the rudder behind the plane, the equilibrium is maintained. The machine during flight, owing to the above causes, describes a series of ascents and descents, after the manner of a sparrow.[1]



aa, elastic aeroplane; *bb*, automatic rudder; *cc*, aerial screw centred at *f*; *d*, frame supporting aeroplane, rudder, and screw; *e*, India-rubber in a state of torsion, attached to hook or crank at *f*. By holding the aeroplane (*aa*) and turning the screw (*cc*) the necessary power is obtained by torsion. — *M. Pénaud, 1872.*

There was one very important element contained in the Pénaud model shown in accompanying cut, and that was the *elasticity of the sustaining surfaces*, which probably had much to do with the success of its flights. Even at the risk of some repetition, another paragraph[2] is here quoted:

As *rigid* aeroplanes and screws were employed in the construction of these models (previously described) they flew in a hap-hazard sort of a way.

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[1] It will occur to the reader that the flight of a sparrow is not conspicuous for its horizontality. Any one who experiments with motorless gliders (see AERONAUTICAL ANNUAL, No. 1, p. 166) made on the Pénaud principle will find the first flights decidedly sparrow-like, but he will also find that by varying the amount of weight carried, the position of the centre of gravity, and the size and angle of the rudder, the undulation of the flights can be made less and less. — *Ed.*

[2] See Encyclopædia Britannica, 9th edition, N.Y., 1879, Vol. IX., p. 321. The italics used in the quotation are in the original.

it being found exceedingly difficult to confer on them the necessary degree of stability fore and aft and laterally. M. Pénaud succeeded in overcoming the difficulty in question by the invention of what he designates his automatic rudder. This consists of a small *elastic* aeroplane placed aft or behind the principal aeroplane, which is also *elastic*. The two elastic aeroplanes extend horizontally and make a slight upward angle with the horizon, the angle made by the smaller aeroplane (the rudder) being slightly in excess of that made by the larger.

As there are several more subjects to be considered in this editorial, more space must not be given to this matter of automatic stability. To say that experiments with models can instruct us concerning it, is almost like stating an axiom.

We come now to the second subject: the disposition of surfaces. The nature of the questions which arise in this connection can best be explained by referring the reader to the previous pages where Mr. Chanute has described the permutations of his surfaces.

Very much of what is now known concerning the disposition of surfaces has been learned from the flights of models. I think that no experimenter will doubt that there is still more to be learned.

When we consider the third subject, the placing of screws, we shall see how models may instruct us in such a manner that undue risks of life and limb may be greatly lessened. The motorless gliding model is acted upon by two forces — gravity and the pressure of the air upon its surfaces. When a motor and propellers are used there is a third force, the thrust of the screws, which has to be considered in all calculations. We are justified in assuming that any self-propelled flying machine must have the excellence of equilibrium of the best gliding machine when at any time its engines are stopped; therefore it is possible to gain knowledge as to the best way of placing the *motor*, by using, in place of the motor, ballast having the weight and general form of the motor which is later to be used.

Where the line of screw-thrust is to come, so that, when this third force is applied, the equilibrium of the machine will not be

seriously compromised, is a matter upon which engineers are not fully agreed, and therefore an amateur may well refrain from expressing an opinion. The difficulty comes in the travel of the centre of air pressure, which is now imperfectly understood.

This much seems probable, that if engineers will furnish working hypotheses, careful laymen may test these in placing the screws on their models, and in that way do useful work.

The air-sailer who in flight first adds the thrust of a screw to the forces he is accustomed to deal with will stand in need of all the knowledge which can be gained from self-propelled models.

The fourth subject is, the curves of surfaces. Lilienthal's article entitled "The Best Shapes for Wings," which is given on previous pages, leaves at present little to say under this head.

The fifth and sixth subjects may be considered together.

The relation of the whole weight of a model to the area of its sustaining surfaces and the relation of the power used to the whole weight sustained are very important matters, and it may be assumed that when model-flying becomes common, many models will be made with removable motors, so that with one motor comparative tests of different forms of models can be made, and useful if not precise data be obtained.

The value of comparative tests made with steam motors would perhaps be impaired by the variations of the power coming from different conditions of the flame in different flights, but with compressed air or liquid carbonic acid the comparative tests would be useful, to say the least.

The seventh subject — the effects of elasticity in sustaining surfaces — gives great scope to experimenters. Those who devote themselves to it can surely help to answer the still unanswered question, Does the feather structure of a bird's wing give to it a certain quality which makes it a better model for us to follow than the featherless wing of the bat? To Lilienthal this seemed to be an open question.

I have tried to make a strong plea in behalf of the flying model. It seems to me that, whatever its limitations may be, it can lessen the risks to life and limb.

ABBOTT LAWRENCE ROTCH.

By the Editor.

Abbott Lawrence Rotch, of Boston and Milton, Mass., whose researches in meteorology are described in the following article, was born in Boston, Jan. 6, 1861.

He is a graduate of the Massachusetts Institute of Technology, Class of '84, Department of Mechanical Engineering. He was a member of the International Jury of Awards for Instruments of Precision at the Paris Exposition of 1889 and was there created a Chevalier of the Legion of Honor. In 1902 he received from the German Emperor the Order of the Prussian Crown, III. Class, and in 1905 the Order of the Red Eagle, III. Class, in recognition of his efforts to advance the knowledge of the atmosphere. He was for ten years an associate editor of the "American Meteorological Journal."

In 1906 he was appointed Professor of Meteorology by Harvard University. He is librarian of the American Academy of Arts and Sciences, a trustee of the Boston Society of Natural History, and has been for nineteen years a member of the Corporation of the Massachusetts Institute of Technology. He is a corresponding or honorary member of various foreign scientific societies and a member of several international committees.

His published contributions to meteorological knowledge have been very numerous. His most recent publication is a valuable addition to aeronautical literature; it is entitled "The Conquest of the Air" (New York, 1910).

By the many who know him Professor Rotch is respected and admired for his devotion to the cause of science, for his generosity in giving credit to his assistants and for his large-mindedness in using his funds for the advancement of knowledge.

(WRITTEN IN 1910.)

THE RELATION OF THE WIND TO AERIAL NAVIGATION.

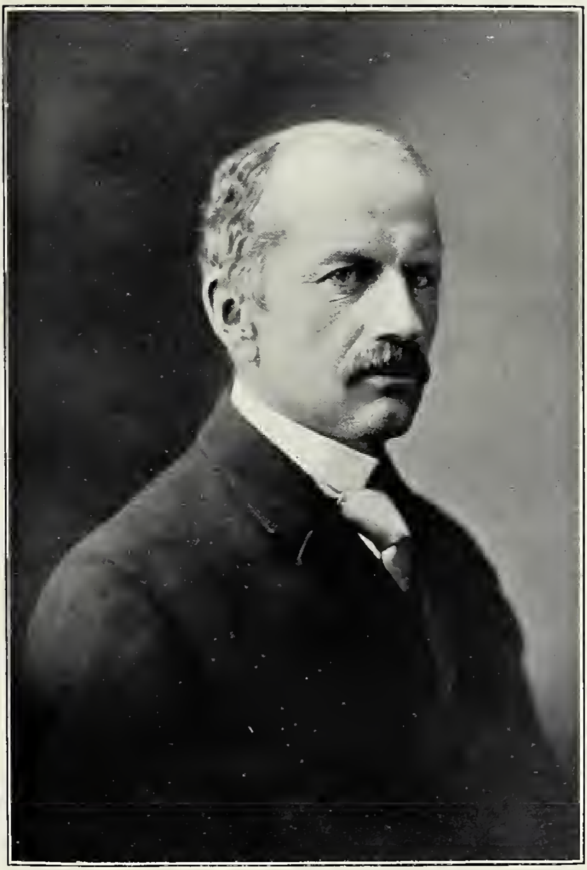
BY PROF. A. LAWRENCE ROTCH.
(*Director of Blue Hill Meteorological Observatory.*)

IN "The Aeronautical Annual" for 1896 the author discussed the mean velocity of the wind at different altitudes, the maximum velocity and pressure, the inclination and direction of the wind and the diurnal changes of velocity and direction in their relation to aeronautics. At that time there were no flying-machines and the dirigible balloon had only been shown to be possible, so that the information given had chiefly a prospective value. The data obtained in the free air were also comparatively meagre, since, except for the observations of clouds which gave the direction and speed of the higher air currents, little knowledge was available. Kites carrying anemometers had been used for about a year at Blue Hill,[1] where the first experiments of the kind took place, but no observations had been made at heights greater than 600 metres, or three times the height of the hill.

At the present time conditions have greatly changed. The advent of numerous flying-machines and dirigible balloons in many countries and their proposed use in peace and war render a knowledge of the aerial currents of great practical importance. The information, however, has not been furnished by aeronauts, but chiefly by meteorologists operating from the ground.

In 1896 the International Meteorological Conference assembled in Paris, impressed by the recent ascensions of sounding balloons to great heights in Europe and the success obtained by kites carrying instruments at Blue Hill Observatory,

[1] See article entitled *The Blue Hill Meteorological Observatory.*



ABBOTT LAWRENCE ROTCH.

Founder and Director of the Blue Hill Meteorological Observatory.

appointed an International Commission for Scientific Aeronautics, which since that time has been collecting data in the free air. Besides several observatories where this is done daily, at some twenty-five places on land and sea throughout the world observations are made with balloons and kites on one or more specified days each month. These observations are centralized and published at Strassburg, and while primarily intended for the elucidation of atmospheric laws, much of the data are of value for aerial navigation. Blue Hill Observatory is the oldest of these aerological stations and the data quoted in this article, which, except for the ocean, pertain to the eastern United States, have been collected by its staff. A discussion of the wind observations obtained at Blue Hill and St. Louis has lately been made by Mr. A. H. Palmer, and some of his figures are cited.

METHODS OF INVESTIGATION. — In order to obtain consecutive observations at a uniform height for a considerable period, it is necessary that they shall be made at a fixed station. Formerly it was thought that the conditions on a mountain-summit were the same as those at an equal height in the free air, but it is now recognized that both temperature and wind are much influenced by the mass of the mountain, the wind being often accelerated just above the obstacle, like water passing over a dam. By sending anemometers attached to kites frequently to or above the desired level, the velocity for a day or a year has been approximately determined at Blue Hill to 3600 metres, and occasionally observations are elsewhere made up to 6000 metres, or $3\frac{3}{4}$ miles. Clouds measured trigonometrically from the ends of a base-line permit the direction and velocity of the air-currents in which they float to be ascertained to a height of 10,000 metres, or $6\frac{1}{4}$ miles. But this method of ascertaining the upper air currents is not always available, for frequently there are no clouds, or the lower strata obscure the upper clouds, and, in any case, the air-currents at successive heights can never be measured at the same time. This, however, can be done in clear weather by pilot-balloons, triangulated like the clouds from a base-line, or from a single station if the rate of

ascent be known. It is believed that the first exact measurements in America of pilot-balloons were made at Blue Hill in 1909, and once a balloon was observed there until it had risen 18,000 metres, or more than 11 miles. Even in cloudy weather, or at night, it is possible to obtain the general drift of the atmosphere up to heights of 16,000 metres (10 miles), or higher, by the so-called "sounding-balloons" which carry automatic instruments that record continuously height, temperature, and the time. The first balloons of this kind in America were sent up from St. Louis in 1904 by the Blue Hill staff, and when they fell to the ground a hundred miles or more away, almost all were found and returned to the Observatory. Knowing the place at which the balloon falls and having an automatic record of the height and duration of the flight, its average height, direction, and speed could be calculated. As the balloons drift towards the east they should be liberated from the interior of the country, and therefore St. Louis was chosen for most of these experiments. But sounding-balloons can be used at sea, provided two are coupled together, for when one bursts and the system falls to the water, the other balloon supports the instrument and serves as a beacon to guide the steamer to its rescue. Both pilot and sounding-balloons and also kites were employed on board a steam yacht sent by M. Teisserenc de Bort and the writer to explore the atmosphere above the tropical Atlantic in 1905–6.

Results of Observations. — First we will consider the increase of wind with altitude, deduced from the various methods of observation described. Blue Hill (200 metres) has a mean velocity for the year of 7.1 metres per second (15.8 miles per hour). The increase of velocity is fastest just above the hill, but the increase continues to the greatest heights. The averages for the year at various heights are as follows: 550 metres, or one-third of a mile above sea-level, 9.8 metres per second, or 21.8 miles per hour; 1000 metres, 10.7 metres per second; 2500 metres, 12.5 metres per second; 3500 metres, 15.5 metres per second; 5400 metres, 24.9 metres per second;

6400 metres, 27.1 metres per second, and 9500 metres (6 miles), 35.8 metres per second, or 80.8 miles per hour. The annual range from summer to winter increases extremely with height as shown by the following table:

Height in metres........	200–1000	1000–3000	3000–5000	5000–7000	7000–9000
Mean vel. in summer, m.p.s. ..	7.5	8.2	10.6	19.1	23.5
Mean vel. in winter, m.p.s. ...	8.8	14.7	21.6	49.3	54.0

From this it will be seen that the velocity of the upper winds in winter is more than double the rate in summer and, in fact, sometimes exceeds 100 metres per second, or 223 miles an hour. The wind-velocity increases nearly twice as fast at night as in the day-time up to about 500 metres, or one-third of a mile. Above that height there is a decrease of velocity, except in winter, up to 1000 metres and then the steady increase which has been noted. The diurnal variation of wind-velocity is well known at low levels on land, where the highest velocity occurs in the afternoon and the least velocity in the early morning, but it is not generally known that these conditions are completely reversed in the free air at the height of 500 metres, where the maximum wind is at night, as already stated.

It is obvious that over the temperate regions of the globe the surface-winds are constantly changing their direction as they blow around the passing areas of high and low barometric pressures. Above these shifting winds the wind is generally westerly, as proved by the drift of the upper clouds and by the balloons sent off from St. Louis, whose mean direction above the height of a mile was from the west-northwest. Whatever the direction of the surface-wind, it had a tendency to become westerly at a height of a couple of thousand metres, a wind from a southerly quarter generally turning in a right-handed direction, whereas a wind from the north turned to the left-hand. In the tropics the wind blows steadily from the northeast, north of the Equator, and from the southeast south of it, and it has been assumed that above these winds counter-trades blew in the opposite directions in order that the atmospheric circulation might be completed. The Franco-American expedition already mentioned confirmed the theory. Above

the northeast trade the wind gradually turned until it became southwest and above the southeast trade there was found an overlying northwest wind. The turning was usually in the direction of the hands of a clock, but sometimes in the opposite direction, and the height at which it occurred varied from a few hundred to several thousand metres. Above the Equator the wind was from the east at all heights.

Practical Applications. — Since the winds above the earth's surface blow much faster than the surface winds, and aerial machines are enormously more bulky than aquatic vehicles of the same carrying capacity, it is evident that the currents in the various levels of the atmosphere are of vastly more importance to the aeronaut than are the ocean currents or surface-winds to the sailor. Moreover, a balloon or flying-machine, wholly immersed in one medium, cannot tack, as a ship, floating in the water, can advance partly into the wind. Consequently a balloon without motive power can only drift with the current and a dirigible balloon or flying-machine must possess a proper speed superior to that of the current in which it floats in order to make headway against it. Hence the necessity in the case of the aerostat, and the advisability in the case of airship or aeronat, to seek a favorable current in the aerial ocean. As this may lie at a considerable height, the aerostat is best able to rise into it, since, as yet, airship and aeronat are limited to heights of about a mile. Probably no aircraft will be able to stem the tremendous velocities of the higher currents, although the diminished density of the air reduces its pressure. Thus an increase of velocity from 9 metres per second to 54 metres per second means an increase of pressure per square metre from 5 kilograms to 210 kilograms, but the actual pressure of this wind would be only 78 kilograms at a height of 8000 metres. The supporting power of the air is reduced in the same ratio, and since the resistance to propulsion against the average wind at any height increases faster than the density diminishes, it follows that, unless a favorable current can be found, navigation at low levels is preferable. Near the ground the wind is more gusty on

account of the obstacles which it encounters, and at night, when there are no ascending currents or changes of temperature, a suitable level for aerial navigation in summer is at the height of 1000 metres, this being a region of little wind and of relative warmth and dryness. In the daytime it is necessary to ascend above the cumulus clouds which mark the limit of the convectional currents. Supposing an aircraft to possess the very moderate speed of 9 metres per second, or 20 miles per hour, it would be truly dirigible at low-levels in the vicinity of Boston on one day in two during the winter half-year and on five days in six during the summer season.[1] Except for the local sea-breezes on our coasts in summer, the surface-winds in these latitudes are too variable to be of practical use in aerial navigation, but, given aircraft which can ascend into the so-called planetary winds at a height of 3000 or 4000 metres and remain in the air for several days, certain high-level international routes appear available. For instance, a spherical balloon, or better a balloon with motive power, which can fulfil these conditions should be able to cross the American continent from west to east and even the Atlantic Ocean at a speed of not less than 15 metres per second from the drift alone. By utilizing the northeast surface trade-wind and starting from the coast of Northern Africa or the adjacent islands, the return passage could be made to the West Indies at the rate of about 12 metres per second, supposing no motive power were used. By ascending sufficiently high the southwest counter-trade would probably furnish an "air-lane" to the eastward between the West Indies and Teneriffe or Madeira. It may be supposed that the International Commission for Scientific Aeronautics by its coöperative work in the interest of science has already accumulated sufficient data to chart aerial routes, comparable to the ocean routes laid down by the various hydrographic offices, and in this era of aerial navigation it is certain that the researches of such aerological stations as Mount Weather and Blue Hill, in America, and Trappes and Lindenberg, in Europe, will have a great practical value.

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[1] If the speed be increased to 30 miles per hour, there will only be about 30 days in winter when the aerial vehicle cannot be propelled in any direction.

1910. *Note.* — The two following articles, first printed in "Nicholson's Journal," November, 1809, and February, 1810, and reprinted in THE AERONAUTICAL ANNUAL for 1895, are especially interesting as showing that even at that time there was at least one man who was intelligently experimenting and giving careful thought and study to the subject of aviation. — ED.

ON AERIAL NAVIGATION.

By SIR GEORGE CAYLEY, BART.

BROMPTON, Sept. 6, 1809.

SIR, I observed in your Journal for last month, that a watchmaker at Vienna, of the name of Degen, has succeeded in raising himself in the air by mechanical means. I waited to receive your present number, in expectation of seeing some farther account of this experiment, before I commenced transcribing the following essay upon aerial navigation, from a number of memoranda which I have made at various times upon this subject. I am induced to request your publication of this essay, because I conceive, that, in stating the fundamental principles of this art, together with a considerable number of facts and practical observations, that have arisen in the course of much attention to this subject, I may be expediting the attainment of an object, that will in time be found of great importance to mankind; so much so, that a new æra in society will commence, from the moment that aerial navigation is familiarly realized.

It appears to me, and I am more confirmed by the success of the ingenious Mr. Degen, that nothing more is necessary, in order to bring the following principles into common practical use, than the endeavours of skilful artificers, who may vary the means of execution, till those most convenient are attained.

Since the days of Bishop Wilkins the scheme of flying by artificial wings has been much ridiculed; and indeed the idea of attaching wings to the arms of a man is ridiculous enough, as the pectoral muscles of a bird occupy more than two-thirds of its whole muscular strength, whereas in man the muscles, that could operate upon wings thus attached, would probably

not exceed one-tenth of his whole mass. There is no proof that, weight for weight, a man is comparatively weaker than a bird; it is therefore probable, if he can be made to exert his whole strength advantageously upon a light surface similarly proportioned to his weight as that of the wing to the bird, that he would fly like the bird, and the ascent of Mr. Degen is a sufficient proof of the truth of this statement.

The flight of a strong man by great muscular exertion, though a curious and interesting circumstance, in as much as it will probably be the first means of ascertaining this power, and supplying the basis whereon to improve it, would be of little use. I feel perfectly confident, however, that this noble art will soon be brought home to man's general convenience, and that we shall be able to transport ourselves and families, and their goods and chattels, more securely by air than by water, and with a velocity of from 20 to 100 miles per hour.

To produce this effect, it is only necessary to have a first mover, which will generate more power in a given time, in proportion to its weight, than the animal system of muscles.

The consumption of coal in a Boulton and Watt's steam engine is only about $5\frac{1}{2}$ lbs. per hour for the power of one horse. The heat produced by the combustion of this portion of inflammable matter is the sole cause of the power generated; but it is applied through the intervention of a weight of water expanded into steam, and a still greater weight of cold water to condense it again. The engine itself likewise must be massy enough to resist the whole external pressure of the atmosphere, and therefore is not applicable to the purpose proposed. Steam engines have lately been made to operate by expansion only, and those might be constructed so as to be light enough for this purpose, provided the usual plan of a large boiler be given up, and the principle of injecting a proper charge of water into a mass of tubes, forming the cavity for the fire, be adopted in lieu of it. The strength of vessels to resist internal pressure being inversely as their diameters, very slight metallic tubes would be abundantly strong, whereas a large boiler must be of great substance to resist a strong pressure. The following

estimate will show the probable weight of such an engine with its charge for one hour.

	lb.
The engine itself from 90 to	100
Weight of inflamed cinders in a cavity presenting about 4 feet surface of tube	25
Supply of coal for one hour	6
Water for ditto, allowing steam of one atmosphere to be $\frac{1}{1800}$ the specific gravity of water	32
	163

I do not propose this statement in any other light than as a rude approximation to truth, for as the steam is operating under the disadvantage of atmospheric pressure, it must be raised to a higher temperature than in Messrs. Boulton and Watt's engine; and this will require more fuel; but if it take twice as much, still the engine would be sufficiently light, for it would be exerting a force equal to raising 550 lb. one foot high per second, which is equivalent to the labour of six men, whereas the whole weight does not much exceed that of one man.

It may seem superfluous to inquire farther relative to first movers for aerial navigation; but lightness is of so much value in this instance, that it is proper to notice the probability that exists of using the expansion of air by the sudden combustion of inflammable powders or fluids with great advantage. The French have lately shown the great power produced by igniting inflammable powders in close vessels; and several years ago an engine was made to work in this country in a similar manner, by the inflammation of spirit of tar. I am not acquainted with the name of the person who invented and obtained a patent for this engine, but from some minutes with which I was favoured by Mr. William Chapman, civil engineer in Newcastle, I find that 80 drops of the oil of tar raised eight hundred weight to the height of 22 inches; hence a one horse power may consume from

10 to 12 pounds per hour, and the engine itself need not exceed 50 pounds weight. I am informed by Mr. Chapman, that this engine was exhibited in a working state to Mr. Rennie, Mr. Edmund Cartwright, and several other gentlemen, capable of appreciating its powers; but that it was given up in consequence of the expense attending its consumption being about eight times greater than that of a steam engine of the same force.

Probably a much cheaper engine of this sort might be produced by a gas-light apparatus, and by firing the inflammable air generated, with a due portion of common air, under a piston. Upon some of these principles it is perfectly clear, that force can be obtained by a much lighter apparatus than the muscles of animals or birds, and therefore in such proportion may aerial vehicles be loaded with inactive matter. Even the expansion steam engine doing the work of six men, and only weighing equal to one, will as readily raise five men into the air, as Mr. Degen can elevate himself by his own exertions; but by increasing the magnitude of the engine, 10, 50, or 500 men may equally well be conveyed; and convenience alone, regulated by the strength and size of materials, will point out the limit for the size of vessels in aerial navigation.

Having rendered the accomplishment of this object probable upon the general view of the subject, I shall proceed to point out the principles of the art itself. For the sake of perspicuity I shall, in the first instance, analyze the most simple action of the wing in birds, although it necessarily supposes many previous steps. When large birds, that have a considerable extent of wing compared with their weight, have acquired their full velocity, it may frequently be observed, that they extend their wings, and without waving them, continue to skim for some time in a horizontal path. Fig. 1, in the Plate, represents a bird in this act.

Let *a b* be a section of the plane of both wings opposing the horizontal current of the air (created by its own motion) which may be represented by the line *c d*, and is the meas-

ure of the velocity of the bird. The angle *b d c* can be increased at the will of the bird, and to preserve a perfectly horizontal path, without the wing being waved, must continually be increased in a complete ratio, (useless at present to enter into) till the motion is stopped altogether; but at one given time the position of the wings may be truly represented by the angle *b d c*. Draw *d e* perpendicular to the plane of the wings, produce the line *e d* as far as required, and from the point *e*, assumed at pleasure in the line *d e*, let fall *e f* perpendicular to *d f*. Then *d e* will represent the whole force of the air under the wing; which being resolved into the two forces *e f* and *f d*, the former represents the force that sustains the weight of the bird, the latter the retarding force by which the velocity of the motion, producing the current *c d*, will continually be diminished. *e f* is always a known quantity, being equal to the weight of the bird, and hence *f d* is also known, as it will always bear the same proportion to the weight of the bird, as the sine of the angle *b d e* bears to its cosine, the angles *d e f*, and *b d c*, being equal. In addition to the retarding force thus received is the direct resistance, which the bulk of the bird opposes to the current. This is a matter to be entered into separately from the principle now under consideration; and for the present may be wholly neglected, under the supposition of its being balanced by a force precisely equal and opposite to itself.

Before it is possible to apply this basis of the principle of flying in birds to the purposes of aerial navigation, it will be necessary to encumber it with a few practical observations. The whole problem is confined within these limits, viz. To make a surface support a given weight by the application of power to the resistance of air. Magnitude is the first question respecting the surface. Many experiments have been made upon the direct resistance of air, by Mr. Robins, Mr. Rouse, Mr. Edgeworth, Mr. Smeaton, and others. The result of Mr. Smeaton's experiments and observations was, that a surface of a square foot met with a resistance of one pound, when it travelled perpendicularly to itself through air at a velocity of 21

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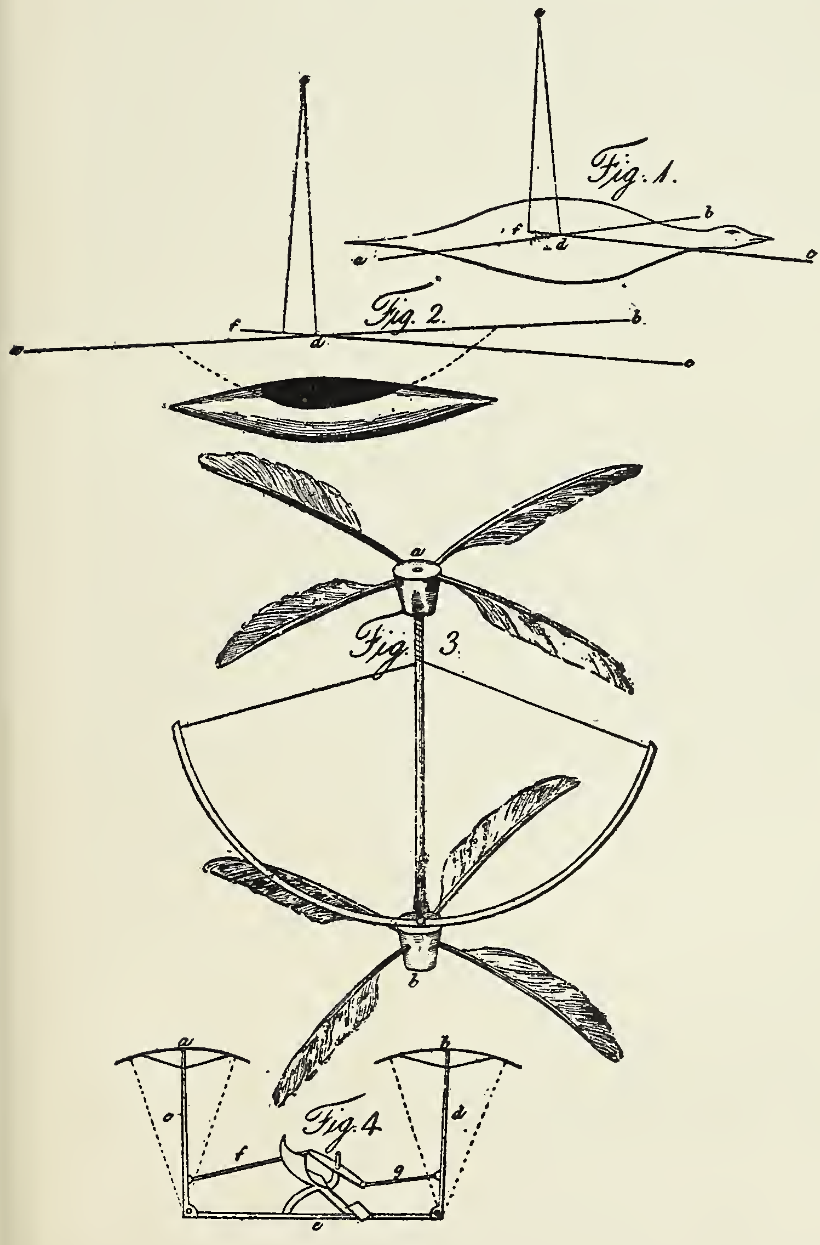


feet per second. I have tried many experiments upon a large scale to ascertain this point. The instrument was similar to that used by Mr. Robins, but the surface used was larger, being an exact square foot, moving round upon an arm about five feet long, and turned by weights over a pulley. The time was measured by a stop watch, and the distance travelled over in each experiment was 600 feet. I shall for the present only give the result of many carefully repeated experiments, which is, that a velocity of 11.538 feet per second generated a resistance of 4 ounces; and that a velocity of 17.16 feet per second gave 8 ounces resistance. This delicate instrument would have been strained by the additional weight necessary to have tried the velocity generating a pressure of one pound per square foot; but if the resistance be taken to vary as the square of the velocity, the former will give the velocity necessary for this purpose at 23.1 feet, the latter 24.28 per second. I shall therefore take 23.6 feet as somewhat approaching the truth.

Having ascertained this point, had our tables of angular resistance been complete, the size of the surface necessary for any given weight would easily have been determined. Theory, which gives the resistance of a surface opposed to the same current in different angles, to be as the squares of the sine of the angle of incidence, is of no use in this case; as it appears from the experiments of the French Academy, that in acute angles, the resistance varies much more nearly in the direct ratio of the sines, than as the squares of the sines of the angles of incidence. The flight of birds will prove to an attentive observer, that, with a concave wing apparently parallel to the horizontal path of the bird, the same support, and of course resistance, is obtained. And hence I am inclined to suspect, that, under extremely acute angles, with concave surfaces, the resistance is nearly similar in them all. I conceive the operation may be of a different nature from what takes place in larger angles, and may partake more of the principle of pressure exhibited in the instrument known by the name of the hydrostatic paradox, a slender filament of the current is constantly received under the anterior edge of the surface, and directed

upward into the cavity, by the filament above it, in being obliged to mount along the convexity of the surface, having created a slight vacuity immediately behind the point of separation. The fluid accumulated thus within the cavity has to make its escape at the posterior edge of the surface, where it is directed considerably downward; and therefore has to overcome and displace a portion of the direct current passing with its full velocity immediately below it; hence whatever elasticity this effort requires operates upon the whole concavity of the surface, excepting a small portion of the anterior edge. This may or may not be the true theory, but it appears to me to be the most probable account of a phenomenon, which the flight of birds proves to exist.

Six degrees was the most acute angle, the resistance of which was determined by the valuable experiments of the French Academy; and it gave $\frac{4}{10}$ of the resistance, which the same surface would have received from the same current when perpendicular to itself. Hence then a superficial foot, forming an angle of six degrees with the horizon, would, if carried forward horizontally (as a bird in the act of skimming) with a velocity of 23.6 feet per second, receive a pressure of $\frac{4}{10}$ of a pound perpendicular to itself. And, if we allow the resistance to increase as the square of the velocity, at 27.3 feet per second it would receive a pressure of one pound. I have weighed and measured the surface of a great many birds, but at present shall select the common rook (*corvus frugilegus*) because its surface and weight are as nearly as possible in the ratio of a superficial foot to a pound. The flight of this bird, during any part of which they can skim at pleasure, is (from an average of many observations) about 34.5 feet per second. The concavity of the wing may account for the greater resistance here received, than the experiments upon plain surfaces would indicate. I am convinced, that the angle made use of in the crow's wing is much more acute than six degrees; but in the observations, that will be grounded upon these data, I may safely state, that every foot of such

curved surface, as will be used in aerial navigation, will receive a resistance of one pound, perpendicular to itself, when carried through the air in an angle of six degrees with the line of its path, at a velocity of about 34 or 35 feet per second.

Let *a b*, fig. 2, represent such a surface or sail made of thin cloth, and containing about 200 square feet (if of a square form the side will be a little more than 14 feet); and the whole of a firm texture. Let the weight of the man and the machine be 200 pounds. Then if a current of wind blew in the direction *c d*, with a velocity of 35 feet per second, at the same time that a cord represented by *c d* would sustain a tension of 21 pounds, the machine would be suspended in the air, or at least be within a few ounces of it (falling short of such support only in the ratio of the sine of the angle of 94 degrees compared with radius; to balance which defect, suppose a little ballast to be thrown out) for the line *d e* represents a force of 200 pounds, which, as before, being resolved into *d f* and *f e*, the former will represent the resistance in the direction of the current, and the latter that which sustains the weight of the machine. It is perfectly indifferent whether the wind blow against the plane, or the plane be driven with an equal velocity against the air. Hence, if this machine were pulled along by a cord *c d*, with a tension of about 21 pounds, at a velocity of 35 feet per second, it would be suspended in a horizontal path; and if in lieu of this cord any other propelling power were generated in this direction, with a like intensity, a similar effect would be produced. If therefore the waft of surfaces advantageously moved, by any force generated within the machine, took place to the extent required, aerial navigation would be accomplished. As the acuteness of the angle between the plane and current increases, the propelling power required is less and less. The principle is similar to that of the inclined plane, in which theoretically one pound may be made to sustain all but an infinite quantity; for in this case, if the magnitude of the surface be increased

ad infinitum, the angle with the current may be diminished, and consequently the propelling force, in the same ratio. In practice, the extra resistance of the car and other parts of the machine, which consume a considerable portion of power, will regulate the limits to which this principle, which is the true basis of aerial navigation, can be carried; and the perfect ease with which some birds are suspended in long horizontal flights, without one waft of their wings, encourages the idea, that a slight power only is necessary.

As there are many other considerations relative to the practical introduction of this machine, which would occupy too much space for any one number of your valuable Journal, I propose, with your approbation, to furnish these in your subsequent numbers; taking this opportunity to observe, that perfect steadiness, safety, and steerage, I have long since accomplished upon a considerable scale of magnitude; and that I am engaged in making some farther experiments upon a machine I constructed last summer, large enough for aerial navigation, but which I have not had an opportunity to try the effect of, excepting as to its proper balance and security. It was very beautiful to see this noble white *bird* sail majestically from the top of a hill to any given point of the plane below it, according to the set of its rudder, merely by its own weight, descending in an angle of about 18 degrees with the horizon. The exertions of an individual, with other avocations, are extremely inadequate to the progress, which this valuable subject requires. Every man acquainted with experiments upon a large scale well knows how leisurely fact follows theory, if ever so well founded. I do therefore hope, that what I have said, and have still to offer, will induce others to give their attention to this subject; and that England may not be backward in rivalling the continent in a more worthy contest than that of arms.

As it may be an amusement to some of your readers to see a machine rise in the air by mechanical means, I will conclude my present communication by describing an instrument of this kind, which any one can construct at the expense of ten minutes labour.

a and *b*, fig. 3, are two corks, into each of which are inserted four wing feathers from any bird, so as to be slightly inclined like the sails of a windmill, but in opposite directions in each set. A round shaft is fixed in the cork *a*, which ends in a sharp point. At the upper part of the cork *b* is fixed a whalebone bow, having a small pivot hole in its centre, to receive the point of the shaft. The bow is then to be strung equally on each side to the upper portion of the shaft, and the little machine is completed. Wind up the string by turning the flyers different ways, so that the spring of the bow may unwind them with their anterior edges ascending; then place the cork with the bow attached to it upon a table, and with a finger on the upper cork press strong enough to prevent the string from unwinding, and taking it away suddenly, the instrument will rise to the ceiling. This was the first experiment I made upon this subject in the year 1796. If in lieu of these small feathers large planes, containing together 200 square feet, were similarly placed, or in any other more convenient position, and were turned by a man, or first mover of adequate power, a similar effect would be the consequence, and for the mere purpose of ascent this is perhaps the best apparatus; but speed is the great object of this invention, and this requires a different structure.

P. S. In lieu of applying the continued action of the inclined plane by means of the rotative motion of flyers, the same principle may be made use of by the alternate motion of surfaces backward and forward; and although the scanty description hitherto published of Mr. Degen's apparatus will scarcely justify any conclusion upon the subject; yet as the principle above described must be the basis of every engine for aerial navigation by mechanical means, I conceive, that the method adopted by him has been nearly as follows. Let A and B, fig. 4, be two surfaces or parachutes, supported upon the long shafts C and D, which are fixed to the ends of the connecting beam E, by hinges. At E, let there be a convenient seat for the aeronaut,

and before him a cross bar turning upon a pivot in its centre, which being connected with the shafts of the parachutes by the rods F and G, will enable him to work them alternately backward and forward, as represented by the dotted lines. If the upright shafts be elastic, or have a hinge to give way a little near their tops, the weight and resistance of the parachutes will incline them so, as to make a small angle with the direction of their motion, and hence the machine rises. A slight heeling of the parachutes toward one side, or an alteration in the position of the weight, may enable the aeronaut to steer such an apparatus tolerably well; but many better constructions may be formed, for combining the requisites of speed, convenience and steerage. It is a great point gained, when the first experiments demonstrate the practicability of an art; and Mr. Degen, by whatever means he has effected this purpose, deserves much credit for his ingenuity.

[From Aero. Ann., 1895.]

ON AERIAL NAVIGATION.

(*From Nicholson's Journal, February, 1810.*)

By Sir George Cayley, Bart.

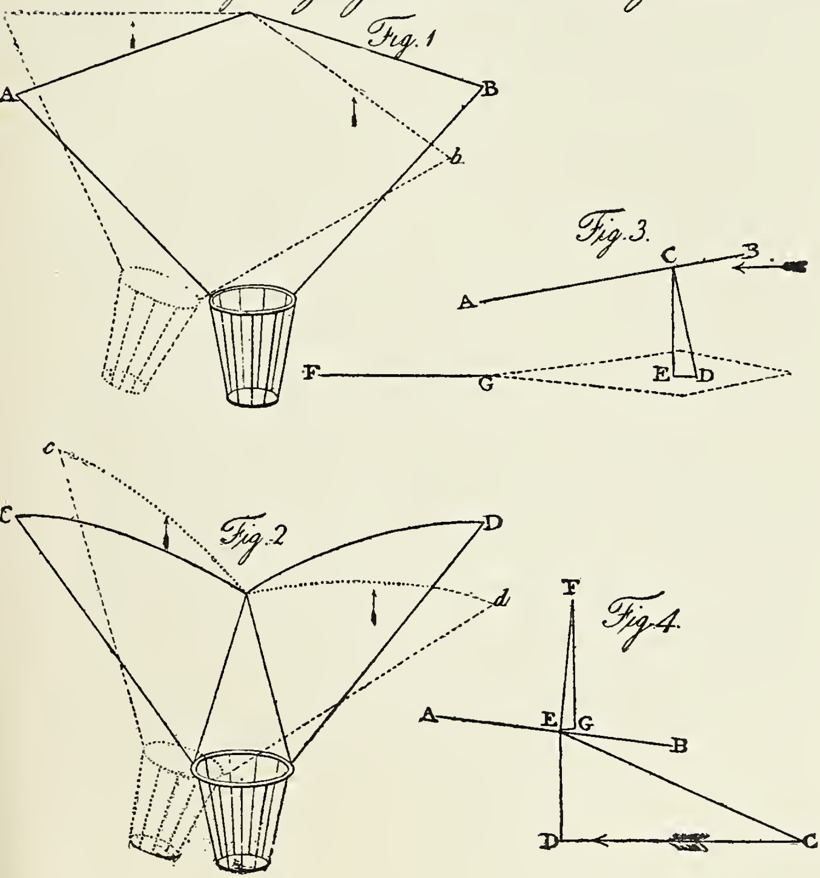
Having, in my former communication, described the general principle of support in aerial navigation, I shall proceed to show how this principle must be applied, so as to be steady and manageable.

Several persons have ventured to descend from balloons in what is termed a parachute, which exactly resembles a large umbrella, with a light car suspended by cords underneath it. Mr. Garnerin's descent in one of these machines will be in the recollection of many; and I make the remark for the purpose of alluding to the continued oscillation, or want of steadiness, which is said to have endangered that bold aeronaut. It is very remarkable, that the only machines of this sort, which have been constructed, are nearly of the worst possible form for producing a steady descent, the purpose for which they are intended. To render this subject more familiar, let us recollect, that in a boat, swimming upon water, its stability or stiffness depends, in general terms, upon the *weight* and distance from the centre of the section elevated above the water, by any given heel of the boat, on one side; and on the *bulk*, and its distance from the centre, which is immersed below the water, on the other side; the combined endeavour of the one to fall, and of the other to swim, produces the desired effect in a well-constructed boat. The centre of gravity of the boat being more or less below the centre of suspension is an additional cause of its stability.

Let us now examine the effect of a parachute represented by A B, Fig. 1, Pl. III. When it has heeled into the position *a b*, the side *a* is become perpendicular to the current, created by the descent, and therefore resists with its greatest power; whereas

Nicholson's Philos. Journal, Vol. XXV. pl. III. p. 81.

Sir G. Cayley, on Aerial Navigation.



the side *b* is become more oblique, and of course its resistance is much diminished. In the instance here represented, the angle of the parachute itself is 144°, and it is supposed to heel 18°, the comparative resistance of the side *a* to the side *b*, will be as the square of the line *a*, as radius, to the square of the sine of the angle of *b* with the current; which, being 54 degrees, gives the resistances nearly in the ratio of 1 to 0.67; and this will be reduced to only 0.544, when estimated in a direction perpendicular to the horizon. Hence, so far as this form of the sail or plane is regarded, it operates directly in opposition to the principle of stability; for the side that is required to fall resists much more in its new position, and that which is required to rise resists much less; therefore complete inversion would be the consequence, if it were not for the weight being suspended so very much below the surface, which, counteracting this tendency, converts the effort into a violent oscillation.

On the contrary, let the surface be applied in the inverted position, as represented at C D, Fig. 2, and suppose it to be heeled to the same angle as before, represented by the dotted lines *c d*. Here the exact reverse of the former instance takes place; for that side, which is required to rise, has gained resistance by its new position, and that which is required to sink has lost it; so that as much power operates to restore the equilibrium in this case, as tended to destroy it in the other: the operation very much resembling what takes place in the common boat.[1]

This angular form, with the apex downward, is the chief basis of stability in aerial navigation; but as the sheet which is to suspend the weight attached to it, in its horizontal path through the air, must present a slightly concave surface in a small angle with the current, this principle can only be used in the lateral extension of the sheet; and this most effectually prevents any rolling of the machine from side to side. Hence, the section of

[1] A very simple experiment will show the truth of this theory. Take a circular piece of writing paper, and folding up a small portion, in the line of two radii, it will be formed into an obtuse cone. Place a small weight in the apex, and letting it fall from any height, it will steadily preserve that position to the ground. Invert it, and, if the weight be fixed, like the life boat, it rights itself instantly.

the inverted parachute, Fig. 2, may equally well represent the cross section of a sheet for aerial navigation.

The principle of stability in the direction of the path of the machine, must be derived from a different source. Let A B, Fig. 3, be a longitudinal section of a sail, and let C be its centre of resistance, which experiment shows to be considerably more forward than the centre of the sail. Let C D be drawn perpendicular to A B, and let the centre of gravity of the machine be at any point in that line, as at D. Then, if it be projected in a horizontal path with velocity enough to support the weight, the machine will retain its relative position, like a bird in the act of skimming; for, drawing C E perpendicular to the horizon, and D E parallel to it, the line C E will, at some particular moment, represent the supporting power, and likewise its opponent the weight; and the line D E will represent the retarding power, and its equivalent, that portion of the projectile force expended in overcoming it: hence, these various powers being exactly balanced, there is no tendency in the machine but to proceed in its path, with its remaining portion of projectile force.

The stability in this position, arising from the centre of gravity being below the point of suspension, is aided by a remarkable circumstance, that experiment alone could point out. In very acute angles with the current it appears, that the centre of resistance in the sail does not coincide with the centre of its surface, but is considerably in front of it. As the obliquity of the current decreases, these centres approach, and coincide when the current becomes perpendicular to the sail. Hence any heel of the machine backward or forward removes the centre of support behind or before the point of suspension; and operates to restore the original position, by a power, equal to the whole weight of the machine, acting upon a lever equal in length to the distance the centre has removed.

To render the machine perfectly steady, and likewise to enable it to ascend and descend in its path, it becomes necessary to add a rudder in a similar position to the tail in birds. Let F G be the section of such a surface, parallel to the current; and let it be capable of moving up and

down upon G, as a centre, and of being fixed in any position. The powers of the machine being previously balanced, if the least pressure be exerted by the current, either upon the upper or under surface of the rudder, according to the will of the aeronaut, it will cause the machine to rise or fall in its path, so long as the projectile or propelling force is continued with sufficient energy. From a variety of experiments upon this subject I find, that, when the machine is going forward with a superabundant velocity, or that which would induce it to rise in its path, a very steady horizontal course is effected by a considerable depression of the rudder, which has the advantage of making use of this portion of sail in aiding the support of the weight. When the velocity is becoming less, as in the act of alighting, then the rudder must gradually recede from this position, and even become elevated, for the purpose of preventing the machine from sinking too much in front, owing to the combined effect of the want of projectile force sufficient to sustain the centre of gravity in its usual position, and of the centre of support approaching the centre of the sail.

The elevation and depression of the machine are not the only purposes, for which the rudder is designed. This appendage must be furnished with a vertical sail, and be capable of turning from side to side, in addition to its other movements, which effects the complete steerage of the vessel.

All these principles, upon which the support, steadiness, elevation, depression, and steerage, of vessels for aerial navigation, depend, have been abundantly verified by experiments both upon a small and a large scale. Last year I made a machine, having a surface of 300 square feet, which was accidentally broken before there was an opportunity of trying the effect of the propelling apparatus; but its steerage and steadiness were perfectly proved, and it would sail obliquely downward in any direction, according to the set of the rudder. Even in this state, when any person ran forward in it, with his full speed, taking advantage of a gentle breeze in front, it would bear upward so strongly as

scarcely to allow him to touch the ground; and would frequently lift him up, and convey him several yards together.

The best mode of producing the propelling power is the only thing, that remains yet untried toward the completion of the invention. I am preparing to resume my experiments upon this subject, and state the following observations, in the hope that others may be induced to give their attention towards expediting the attainment of this art.

The act of flying is continually exhibited to our view; and the principles upon which it is effected are the same as those before stated. If an attentive observer examines the waft of a wing, he will perceive, that about one third part, toward the extreme point, is turned obliquely backward; this being the only portion, that has velocity enough to overtake the current, passing so rapidly beneath it, when in this unfavourable position. Hence this is the only portion that gives any propelling force.

To make this more intelligible, let A B, Fig. 4, be a section of this part of the wing. Let C D represent the velocity of the bird's path, or the current, and E D that of the wing in its waft: then C E will represent the magnitude and direction of the compound or actual current striking the under surface of the wing. Suppose E F, perpendicular to A B, to represent the whole pressure; E G being parallel to the horizon, will represent the propelling force; and G F, perpendicular to it, the supporting power. A bird is supported as effectually during the return as during the beat of its wing; this is chiefly effected by receiving the resistance of the current under that portion of the wing next the body where its receding motion is so slow as to be of scarcely any effect. The extreme portion of the wing, owing to its velocity, receives a pressure downward and obliquely forward, which forms a part of the propelling force; and at the same time, by forcing the hinder part of the middle portion of the wing downward, so increases its angle with the current, as to enable it still to receive nearly its usual pressure from beneath.

As the common rook has its surface and weight in the ratio

of a square foot to a pound, it may be considered as a standard for calculations of this sort; and I shall therefore state, from the average of many careful observations, the movements of that bird. Its velocity, represented by C D, Fig. 4, is 34.5 feet per second. It moves its wing up and down once in flying over a space of 12.9 feet. Hence, as the centre of resistance of the extreme portion of the wing moves over a space of 0.75 of a foot each beat or return, its velocity is about 4 feet per second, represented by the line E D. As the wing certainly overtakes the current, it must be inclined from it in an angle something less than 7°, for at this angle it would scarcely be able to keep parallel with it, unless the waft downward were performed with more velocity than the return; which may be and probably is the case, though these movements appear to be of equal duration. The propelling power, represented by E G, under these circumstances, cannot be equal to an eighth part of the supporting power G F, exerted upon this portion of the wing; yet this, together with the aid from the return of the wing, has to overcome all the retarding power of the surface, and the direct resistance occasioned by the bulk of the body.

It has been before suggested, and I believe upon good grounds, that very acute angles vary little in the degree of resistance they make under a similar velocity of current. Hence it is probable, that this propelling part of the wing receives little more than its common proportion of resistance, during the waft downward. If it be taken at one-third of the whole surface, and one-eighth of this be allowed as the propelling power, it will only amount to one twenty-fourth of the weight of the bird; and even this is exerted only half the duration of the flight. The power gained in the return of the wing must be added, to render this statement correct, and it is difficult to estimate this; yet the following statement proves, that a greater degree of propelling force is obtained, upon the whole, than the foregoing observations will justify. Suppose the largest circle that can be described in the breast of a crow, to be 12 inches in area. Such a surface, moving at the velocity of 34.5 feet per second, would meet a resistance of 0.216 of a pound, which, reduced by the proportion of the

resistance of a sphere to its great circle (given by Mr. Robins as 1 to 2.27) leaves a resistance of 0.095 of a pound, had the breast been hemispherical. It is probable however, that the curve made use of by Nature to avoid resistance, being so exquisitely adapted to its purpose, will reduce this quantity to one half less than the resistance of the sphere, which would ultimately leave 0.0475 of a pound as somewhat approaching the true resistance. Unless therefore the return of the wing gives a greater degree of propelling force than the beat, which is improbable, no such resistance of the body could be sustained. Hence, though the eye cannot perceive any distinction between the velocities of the beat and return of the wing, it probably exists, and experiment alone can determine the proper ratios between them.

From these observations we may, however, be justified in the remark — that the act of flying, when properly adjusted by the Supreme Author of every power, requires less exertions than, from the appearance, is supposed.

INTRODUCTION TO MR. WENHAM'S PAPER.

THE following paper, "On Aerial Locomotion and the Laws by which Heavy Bodies impelled through Air are Sustained," was read by F. H. Wenham, Esq., at the first meeting of the Aeronautical Society of Great Britain, held on the 27th day of June, 1866. His Grace the Duke of Argyll in the Chair.

Referring to this paper, Mr. John H. Ledeboer in the December, 1908, issue of English AERONAUTICS writes as follows:

"It is not possible to give even a *résumé* of this momentous paper in the short space at my disposal; I would only most strongly urge every student of aviation to read it for himself, and to re-read it; for almost every word it contains holds good at the present day, and might, with great advantage, have been studied by the majority of budding aviators whose failures are of such frequent occurrence."

FRANCIS HERBERT WENHAM DIED IN FOLKESTONE, ENGLAND, AUGUST 11, 1908, AT THE AGE OF EIGHTY-FOUR.

(First printed in The Annual Report of The Aeronautical Society of Great Britain, 1866. Reprinted in the Aeronautical Annual, 1895.)

WENHAM ON AERIAL LOCOMOTION.

The resistance against a surface of a defined area, passing rapidly through yielding media, may be divided into two opposing forces. One arising from the cohesion of the separated particles; and the other from their weight and inertia, which, according to well-known laws, will require a constant power to set them in motion.

In plastic substances, the first condition, that of cohesion, will give rise to the greatest resistance. In water this has very little retarding effect, but in air, from its extreme fluidity, the cohesive force becomes inappreciable, and all resistances are caused by its weight alone; therefore, a weight, suspended from a plane surface, descending perpendicularly in air, is limited in its rate of fall by the weight of air that can be set in motion in a given time.

If a weight of 150 lbs. is suspended from a surface of the same number of square feet, the uniform descent will be 1,300 feet per minute, and the force given out and expended on the air, at this rate of fall, will be nearly six horse-power; and, conversely, this same speed and power must be communicated to the surface to keep the weight sustained at a fixed altitude. As the surface is increased, so does the rate of descent and its accompanying power, expended in a given time, decrease. It might, therefore, be inferred that, with a sufficient extent of surface reproduced, or worked up to a higher altitude, a man might by his exertions raise himself for a time, while the surface descends at a less speed.

A man, in raising his own body, can perform 4,250 units of work — that is, this number of pounds raised one foot high per minute — and can raise his own weight — say, 150 lbs. — twenty-two feet per minute. But at this speed the atmospheric resistance is so small that 120,000 square feet would be required to balance his exertions, making no allowance for weight beyond his own body.

We have thus reasons for the failure of the many misdirected attempts that have, from time to time, been made to raise weights perpendicularly in the air by wings or descending surfaces. Though the flight of a bird is maintained by a constant reaction or abutment against an enormous weight of air in comparison with the weight of its own body, yet, as will be subsequently shown, the support upon that weight is not necessarily commanded by great extent of wing-surface, but by the direction of motion.

One of the first birds in the scale of flying magnitude is the pelican. It is seen in the streams and estuaries of warm climates, fish being its only food. On the Nile, after the inundation, it arrives in flocks of many hundreds together, having migrated from long distances. A specimen shot was found to weigh twenty-one pounds, and measured ten feet across the wings, from end to end. The pelican rises with much difficulty, but, once on the wing, appears to fly with very little exertion, notwithstanding its great weight. Their mode of progress is peculiar and graceful. They fly after a leader, in one single train. As he rises or descends, so his followers do the same in succession, imitating his movements precisely. At a distance, this gives them the appearance of a long undulating ribbon, glistening under the cloudless sun of an oriental sky. During their flight they make about seventy strokes per minute with their wings. This uncouth-looking bird is somewhat whimsical in its habits. Groups of them may be seen far above the earth, at a distance from the river-side, *soaring*, apparently for their own pleasure. With outstretched and motionless wings, they float serenely, high in the atmosphere, for more than an hour together, traversing the same locality in circling

movements. With head thrown back, and enormous bills resting on their breasts, they almost seem asleep. A few easy strokes of their wings each minute, as their momentum or velocity diminishes, serves to keep them sustained at the same level. The effort required is obviously slight, and not confirmatory of the excessive amount of power said to be requisite for maintaining the flight of a bird of this weight and size. The pelican displays no symptom of being endowed with great strength, for when only slightly wounded it is easily captured, not having adequate power for effective resistance, but heavily flapping the huge wings, that should, as some imagine, give a stroke equal in vigour to the kick of a horse.

During a calm evening, flocks of spoonbills take their flight directly up the river's course; as if linked together in unison, and moved by the same impulse, they alter not their relative positions, but at less than fifteen inches above the water's surface, they speed swiftly by with ease and grace inimitable, a living sheet of spotless white. Let one circumstance be remarked, — though they have fleeted past at a rate of near thirty miles an hour, so little do they disturb the element in which they move, that not a ripple of the placid bosom of the river, which they almost touch, has marked their track. How wonderfully does their progress contrast with that of creatures who are compelled to drag their slow and weary way against the fluid a thousandfold more dense, flowing in strong and eddying current beneath them.

Our pennant droops listlessly, the wished-for north wind cometh not. According to custom we step on shore, gun in hand. A flock of white herons, or "buffalo-birds," almost within our reach, run a short distance from the pathway as we approach them. Others are seen perched in social groups upon the backs of the apathetic and mud-begrimed animals whose name they bear. Beyond the ripening dhourra crops which skirt the river-side, the land is covered with immense numbers of blue pigeons, flying to and fro in shoals, and searching for food with restless diligence. The musical whistle from the pinions of the wood-doves sounds cheerily, as they dart past

with the speed of an arrow. Ever and anon are seen a covey of the brilliant, many-coloured partridges of the district, whose *long and pointed wings* give them a strength and duration of flight that seems interminable, alighting at distances beyond the possibility of marking them down, as we are accustomed to do with their plumper brethren at home. But still more remarkable is the spectacle which the sky presents. As far as the eye can reach it is dotted with birds of prey of every size and description. Eagles, vultures, kites and hawks, of manifold species, down to the small, swallow-like, insectivorous hawk common in the Delta, which skims the surface of the ground in pursuit of its insect prey. None seem bent on going forward, but all are soaring leisurely round over the same locality, as if the invisible element which supports them were their medium of rest as well as motion. But mark that object sitting in solitary state in the midst of yon plain: what a magnificent eagle! An approach to within eighty yards arouses the king of birds from his apathy. He partly opens his enormous wings, but stirs not yet from his station. On gaining a few feet more he begins to *walk* away, with half-expanded, but motionless wings. Now for the chance fire! A charge of No. 3 from 11 bore rattles audibly but ineffectively upon his densely feathered body; his walk increases to a run, he gathers speed with his slowly-waving wings, and eventually leaves the ground. Rising at a gradual inclination, he mounts aloft and sails majestically away to his place of refuge in the Lybian range, distant at least five miles from where he rose. Some fragments of feathers denote the spot where the shot had struck him. The marks of his claws are traceable in the sandy soil, as, at first with firm and decided digs, he forced his way, but as he lightened his body and increased his speed with the aid of his wings, the imprints of his talons gradually merged into long scratches. The measured distance from the point where these vanished, to the place where he had stood, proved that with all the stimulus that the shot must have given to his exertions, he had been compelled to run full twenty yards before he could raise himself from the earth.

Again the boat is under weigh, though the wind is but just sufficient to enable us to stem the current. An immense kite is soaring overhead, scarcely higher than the top of our lateen yard, affording a fine opportunity for contemplating his easy and unlaboured movements. The cook has now thrown overboard some offal. With a solemn swoop the bird descends and seizes it in his talons. How easily he rises again with motionless expanded wings, the mere force and momentum of his *descent* serving to raise him again to more than half-mast high. Observe him next, with lazy flapping wings, and head turned under his body; he is placidly devouring the pendant morsel from his foot, and calmly gliding onwards.

The Nile abounds with large aquatic birds of almost every variety. During a residence upon its surface for nine months out of the year, immense numbers have been seen to come and go, for the majority of them are migratory. Egypt being merely a narrow strip of territory, passing through one of the most desert parts of the earth, and rendered fertile only by the periodical rise of the waters of the river, it is probable that these birds make it their grand thoroughfare into the rich districts of Central Africa.

On nearing our own shores, steaming against a moderate head-wind, from a station abaft the wheel the movements of some half-dozen gulls are observed, following in the wake of the ship, in patient expectation of any edibles that may be thrown overboard. One that is more familiar than the rest comes so near at times that the winnowing of his wings can be heard; he has just dropped astern, and now comes on again. With the axis of his body exactly at the level of the eyesight, his every movement can be distinctly marked. He approaches to within ten yards, and utters his wild plaintive note, as he turns his head from side to side, and regards us with his jet black eye. But where is the angle or upward rise of his wings, that should compensate for his descending tendency, in a yielding medium like air? The incline cannot be detected, for, to all appearance, his wings are edgewise, or parallel to his line of motion, and he appears to skim along a *solid* support. No

smooth-edged rails, or steel-tired wheels, with polished axles revolving in well oiled brasses, are needed here for the purpose of diminishing friction, for Nature's machinery has surpassed them all. The retarding effects of gravity in the creature under notice, are almost annulled, for he is gliding forward upon a *frictionless* plane. There are various reasons for concluding that the direct flight of many birds is maintained with a much less expenditure of power, for a high speed, than by any mode of progression.

The first subject for consideration is the proportion of surface to weight, and their combined effect in descending perpendicularly through the atmosphere. The datum is here based upon the consideration of *safety*, for it may sometimes be needful for a living being to drop passively, without muscular effort. One square foot of sustaining surface, for every pound of the total weight, will be sufficient for security.

According to Smeaton's table of atmospheric resistances, to produce a force of *one pound* on a square foot, the wind must move against the plane (or, which is the same thing, the plane against the wind), at the rate of twenty-two feet per second, or 1,320 feet per minute, equal to fifteen miles per hour. The resistance of the air will now balance the weight on the descending surface, and, consequently, it cannot exceed that speed. Now, twenty-two feet per second is the velocity acquired at the *end* of a fall of eight feet — a height from which a well-knit man or animal may leap down without much risk of injury. Therefore, if a man with parachute weigh together 143 lbs., spreading the same number of square feet of surface contained in a circle fourteen and a half feet in diameter, he will descend at perhaps an unpleasant velocity, but with safety to life and limb.

It is a remarkable fact how this proportion of wing-surface to weight extends throughout a great variety of the flying portion of the animal kingdom, even down to hornets, bees, and other insects. In some instances, however, as in the gallinaceous tribe, including pheasants, this area is somewhat exceeded, but they are known to be very poor flyers. Residing as they do

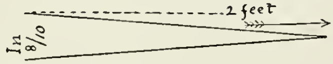
chiefly on the ground, their wings are only required for short distances, or for raising them or easing their descent from their roosting-places in forest trees, the *shortness* of their wings preventing them from taking extended flights. The wing-surface of the common swallow is rather more than in the ratio of *two* square feet per pound, but having also great length of pinion, it is both swift and enduring in its flight. When on a rapid course this bird is in the habit of furling its wings into a narrow compass. The greater extent of surface is probably needful for the continual variations of speed and instant stoppages requisite for obtaining its insect food.

On the other hand, there are some birds, particularly of the duck tribe, whose wing-surface but little exceeds *half* a square foot, or seventy-two inches per pound, yet they may be classed among the strongest and swiftest of flyers. A weight of one pound, suspended from an area of this extent, would acquire a velocity due to a fall of 16 feet — a height sufficient for the destruction or injury of most animals. But when the plane is urged forward horizontally, in a manner analogous to the wings of a bird during flight, the sustaining power is greatly influenced by *the form and arrangement* of the surface.

In the case of *perpendicular* descent, as a parachute, the sustaining effect will be much the same, whatever the figure of the outline of the superficies may be, and a circle perhaps affords the best resistance of any. Take for example a circle of 20 square feet (as possessed by the pelican) loaded with as many pounds. This, as just stated, will limit the rate of perpendicular descent to 1,320 feet per minute. But instead of a circle 61 inches in diameter, if the area is bounded by a parallelogram 10 feet long by 2 feet broad, and whilst at perfect freedom to descend perpendicularly, let a force be applied exactly in a horizontal direction, so as to carry it edgeways, with the long side foremost, at a forward speed of 30 miles per hour — just double that of its passive descent: the rate of fall under these conditions will be decreased most remarkably, probably to less than $\frac{1}{15}$th part, or 88 feet per minute, or one mile per hour.

The annexed line represents transversely the plane 2 feet

wide and 10 feet long, moving in the direction of the arrow



with a forward speed of 30 miles per hour, or 2,640 feet per minute, and descending at 88 feet per minute, the ratio being as 1 to 30. Now, the particles of air, caught by the forward edge of the plane, must be carried down $\frac{8}{10}$ths of an inch before they leave it. This stratum, 10 feet wide and 2,640 long, will weigh not less than 134 lbs.; therefore the weight has continually to be moved downwards, 88 feet per minute, from a state of absolute rest. If the plane, with this weight and an upward rise of $\frac{8}{10}$ths of an inch, be carried forward at a rate of 30 miles per hour, it will be maintained at the same level without descending.

The following illustrations, though referring to the action of surfaces in a denser fluid, are yet exactly analogous to the conditions set forth in air: —

Take a stiff rod of wood, and nail to its end at right angles a thin lath or blade, about two inches wide. Place the rod square across the thwarts of a rowing-boat in motion, letting a foot or more of the blade hang perpendicularly over the side into the water. The direct amount of resistance of the current against the flat side of the blade may thus be felt. Next slide the rod to and fro thwart ship, keeping all square; the resistance will now be found to have increased enormously; indeed, the boat can be entirely stopped by such an appliance. Of course the same experiment may be tried in a running stream.

Another familiar example may be cited in the lee-boards and sliding keels used in vessels of shadow draught, *which act precisely on the same principle as the plane or wing-surface of a bird when moving in air.* These surfaces, though parallel to the line of the vessel's course, enable her to carry a heavy press of sail without giving way under the side pressure, or making lee-way, so great is their resistance against the rapidly passing body of water, which cannot be deflected sideways at a high speed.

The succeeding experiments will serve further to exemplify

the action of the same principle. Fix a thin blade, say one inch wide and one foot long, with its plane exactly midway and at right angles, to the end of a spindle or rod. On thrusting this through a body of water, or immersing it in a stream running in the direction of the axis of the spindle, the resistance will be simply that caused by the water against the mere superficies of the blade. Next put the spindle and blade in rapid rotation. The retarding effect against direct motion will now be increased near *tenfold*, and is equal to that due *to the entire area of the circle of revolution.* By trying the effect of blades of various widths, it will be found that, for the purpose of effecting the maximum amount of resistance, the more rapidly the spindle revolves the narrower may be the blade. There is a specific ratio between the *width* of the blade and its *velocity.* It is of some importance that this should be precisely defined, not only for its practical utility in determining the best proportion of width to speed in the blades of screw-propellers, but also for a correct demonstration of the principles involved in the subject now under consideration; for it may be remarked that the swiftest-flying birds possess extremely long and *narrow* wings, and the slow, heavy flyers short and wide ones.

In the early days of the screw-propeller, it was thought requisite, in order to obtain the advantage of the utmost extent of surface, that the end-view of the screw should present no opening, but appear as a complete disc. Accordingly, some were constructed with one or two threads, making an entire or two half-revolutions; but this was subsequently found to be a mistake. In the case of the two blades, the length of the screw was shortened, and consequently the width of the blades reduced, with increased effect, till each was brought down to considerably less than *one-sixth* of the circumference or area of the entire circle; the maximum speed was then obtained. Experiment has also shown that the effective propelling area of the two-bladed screw is tantamount to its entire circle of revolution, and is generally estimated as such.

Many experiments tried by the author, with various forms of screws, applied to a small steam-boat, led to the same conclu-

sion — that the two blades of one-sixth of the circle gave the best result.

All screws reacting on a fluid such as water, must cause it to yield to some extent; this is technically known as "slip," and whatever the ratio or per-centage on the speed of the boat may be, it is tantamount to *just so much loss of propelling power* — this being consumed in giving motion to the water instead of the boat.

On starting the engine of the steam-boat referred to, and grasping a mooring-rope at the stern, it was an easy matter to hold it back with one hand, though the engine was equal in power to five horses, and the screw making more than 500 revolutions per minute. The whole force of the steam was absorbed in "slip," or in giving motion to the column of water; but let her go, and allow the screw to find an abutment on a fresh body of water, not having received a gradual motion, and with its *inertia undisturbed* when running under full way, the screw worked almost as if in a solid nut, the "slip" amounting to only eleven per cent.

The laws which control the action of inclined surfaces, moving either in straight lines or circles in *air*, are identical, and serve to show the inutility of attempting to raise a heavy body in the atmosphere by means of rotating vanes or a screw acting vertically; for unless the ratio of surface compared to weight is exceedingly extensive, the whole power will be consumed in "slip," or in giving a downward motion to the column of air. Even if a sufficient force is obtained to keep a body suspended by such means, yet, after the desired altitude is arrived at, *no further ascension* is required; there the apparatus is to remain stationary as to level, and its position on the constantly yielding support can only be maintained at an enormous expenditure of power, for the screw cannot obtain a hold upon a *fresh and unmoved* portion of air in the same manner as it does upon the body of water when propelling the boat at full speed; its action under these conditions is the same as when the boat is held fast, in which case, although the engine is working up to its usual rate, the tractive power is almost annulled.

Some experiments made with a screw, or pair of inclined vanes acting vertically in air, were tried, in the following manner. To an upright post was fixed a frame, containing a bevil wheel and pinion, multiplying in the ratio of three to one. The axle of the wheel was horizontal, and turned by a handle of five-and-a-half inches radius. The spindle of the pinion rotated vertically, and carried two driving-pins at the end of a cross-piece, so that the top resembled the three prongs of a trident. The upright shaft of the screw was bored hollow to receive the middle prong, while the two outside ones took a bearing against a driving-bar, at right angles to the lower end of the shaft, the top of which ended in a long iron pivot, running in a socket fixed in a beam overhead; it could thus rise and fall about two inches with very little friction. The top of the screw-shaft carried a cross-arm, with a blade of equal size at each extremity, the distance from end to end being six feet. The blades could be adjusted at any angle by clamping-screws. Both their edges, and the arms that carried them, were bevilled away to a sharp edge to diminish the effects of atmospheric resistance. A wire stay was taken from the base of each blade to the bottom of the upright shaft, to give rigidity to the arms, and to prevent them from springing upwards. With this apparatus experiments were made with weights attached to the upright screw-shaft, and the blades set at different pitches, or angles of inclination. When the vanes were rotated rapidly, they rose and floated on the air, carrying the weights with them. Much difficulty was experienced in raising a heavy weight by a comparatively small extent of surface, moving at a high velocity; the "slip" in these cases being so great as to absorb all the power employed. The utmost effect obtained in this way was to raise a weight of six pounds on one square foot of sustaining surface, the planes having been set at a coarse pitch. To keep up the rotation, required about half the power a man could exert.

The ratio of weight to sustaining surface was next arranged in the proportion approximating to that of birds. Two of the experiments are here quoted, which gave the most satisfactory

result. Weight of wings and shaft, $17\frac{1}{2}$ oz.; area of two wings, 121 inches — equal to 110 square inches per pound. The annexed figures are given approximately, in order to avoid decimal fractions: —

	No. of revolutions per minute.	Mean sustaining speed. Miles per hour.	Feet per minute.	Pitch or angle of rise in one revolution. Inches.	Ratio of pitch to speed.	Slip per cent.
1st Experiment.	210	38	3,360	26	$\frac{1}{8}$th nearly	$12\frac{1}{2}$
2nd Do.	240	44	3,840	15	$\frac{1}{13}$th Do.	8

The power required to drive was nearly the same in both experiments — about equal to one-sixteenth part of a horse-power, or the third part of the strength of a man, as estimated by a constant force on the handle of twelve pounds in the first experiment, and ten in the second, the radius of the handle being five-and-a-half inches, and making seventy revolutions per minute in the first case, and eighty in the other.

These experiments are so far satisfactory in showing the small pitch or angle of rise required for sustaining the weight stated, and demonstrating the principle before alluded to, of the slow descent of planes moving horizontally in the atmosphere at high velocities; but the question remains to be answered. concerning the disposal of the excessive power consumed in raising a weight not exceeding that of a carrier pigeon, for unless this can be satisfactorily accounted for, there is but little prospect of finding an available power, of sufficient energy in its application to the mechanism, for raising apparatus, either experimental or otherwise, in the atmosphere. In the second experiment, the screw-shaft made 240 revolutions, consequently, one vane (there being two) was constantly passing over the *same spot* 480 times each minute, or eight times in a second. This caused a descending current of air, moving at the rate of near four miles per hour, almost sufficient to blow a candle out placed three feet underneath. This is the result of "slip," and

the giving both a downward and rotary motion to this column of air, will account for a great part of the power employed, as the whole apparatus performed the work of a blower. If the wings, instead of travelling in a circle, could have been urged continually forward in a straight line in a fresh and unmoved body of air the " slip " would have been so inconsiderable, and the pitch consequently, reduced to such a small angle, as to add but little to the direct forward atmospheric resistance of the edge.

The small flying screws, sold as toys, are well known. It is an easy matter to determine approximately the force expended in raising and maintaining them in the atmosphere. The following is an example of one constructed of tin-plate with three equidistant vanes. This was spun by means of a cord, wound round a wooden spindle, fitted into a forked handle as usual. The outer end of the coiled string was attached to a small spring steelyard, which served as a handle to pull it out by. The weight, or degree at which the index had been drawn, was *afterwards* ascertained by the mark left thereon by a pointed brass wire. It is not necessary to know the *time* occupied in drawing out the string, as this item in the estimate may be taken as the duration of the ascent; for it is evident that if the same force is re-applied at the descent, it would rise again, and a repeated series of these impulses will represent the power required to prolong the flight of the instrument. It is, therefore, requisite to know the length of string, and the force applied in pulling it out. The following are the data: —

Diameter of screw	$8\frac{1}{2}$ inches.
Weight of ditto	396 grains.
Length of string drawn out	2 feet.
Force employed	8 lbs.
Duration of flight	16 seconds.

From this it may be computed that, in order to maintain the flight of the instrument, a constant force is required of near sixty foot-pounds per minute — in the ratio of about three

horse-power for each hundred pounds raised by such means. The force is perhaps over-estimated for a larger screw, for as the size and weight is increased, the power required would be less than in this ratio. The result would be more satisfactory if tried with a sheet-iron screw, impelled by a descending weight.

Methods analogous to this have been proposed for attempting aerial locomotion; but experiment has shown that a screw rotating in the air is an imperfect principle for obtaining the means of flight, and supporting the needful weight, for the power required is enormous. Suppose a machine to be constructed, having some adequate supply of force, the screw rotating vertically at a certain velocity will raise the whole. When the desired altitude is obtained, nearly the same velocity of revolution, and the same excessive power, must be continued, and consumed *entirely in "slip,"* or in drawing down a rapid current of air.

If the axis of the screw is slightly inclined from the perpendicular, the whole machine will travel forward. The "slip," and consequently the power, is somewhat reduced under these conditions; but a swift forward speed cannot be effected by such means, for the resistance of the inclined disc of the screw will be very great, far exceeding any form assimilating to the edge of the wing of a bird. But, arguing on the supposition that a forward speed of thirty miles an hour might thus be obtained, even then nearly all the power would be expended in giving an unnecessary and rapid revolution to an immense screw, capable of raising a weight, say of 200 pounds. The weight alone of such a machine must cause it to fail, and every revolution of the screw is a subtraction from the much-desired direct forward speed. A simple narrow blade, or inclined plane, propelled in a direct course at *this* speed — which is amply sufficient for sustaining heavy weights — is the best, and, in fact, the only means of giving the maximum amount of supporting power with the least possible degree of "slip," and direct forward resistance. Thousands of examples in Nature testify its success, and show

the principle in perfection; — apparently the only one, and therefore beyond the reach of amendment, the wing of a bird, combining a propelling and supporting organ in one, each perfectly efficient in its mechanical action.

This leads to the consideration of the amount of power requisite to maintain the flight of a bird. Anatomists state that the pectoral muscles for giving motion to the wings are excessively large and strong; but this furnishes no proof of the expenditure of a great amount of force in the act of flying. The wings are hinged to the body like two powerful levers, and some counteracting force of a *passive* nature, acting like a spring under tension, must be requisite merely to balance the weight of the bird. It cannot be shown that, while there is no active motion, there is any real exertion of muscular force; for instance, during the time when a bird is soaring with motionless wings. This must be considered as a state of equilibrium, the downward spring and elasticity of the wings serving to support the body; the muscles, in such a case, performing like stretched india-rubber springs would do. The motion or active power required for the performance of flight must be considered exclusive of this.

It is difficult, if not impossible, by any form of dynamometer, to ascertain the precise amount of force given out by the wings of birds; but this is perhaps not requisite in proof of the principle involved, for when the laws governing their movements in air are better understood, it is quite possible to demonstrate, by isolated experiments, the amount of power required to sustain and propel a given weight and surface at any speed.

If the pelican referred to as weighing twenty-one pounds, with near the same amount of wing-area in square feet, were to descend perpendicularly, it would fall at the rate of 1,320 feet per minute, being limited to this speed by the resistance of the atmosphere.

The standard generally employed in estimating power is by the rate of descent of a weight. Therefore, the weight of the bird being 21 pounds, which, falling at the above speed will expend a force on the air set in motion nearly equal to one

horse (.84 HP.) or that of 5 men; and conversely, to raise this weight again perpendicularly upon a yielding support like air, would require even more power than this expression, which it is certain that a pelican does not possess; nor does it appear that any *large* bird has the faculty of raising itself on the wing *perpendicularly* in a still atmosphere. A pigeon is able to accomplish this nearly, mounting to the top of a house in a very narrow compass; but the exertion is evidently severe, and can only be maintained for a short period. For its size, this bird has great power of wing; but this is perhaps far exceeded in the humming-bird, which, by the extremely rapid movements of its pinions, sustains itself for more than a minute in still air in one position. The muscular force required for this feat is much greater than for any other performance of flight. The body of the bird at the time is nearly vertical. The wings uphold the weight, not by striking vertically downwards upon the air, but as inclined surfaces reciprocating horizontally like a screw, but wanting in its continuous rotation in one direction, and, in consequence of the loss arising from rapid alternations of motion, the power required for the flight will exceed that specified in the screw experiment before quoted, viz.: three horse-power for every 100 pounds raised.

We have here an example of the exertion of enormous animal force expended in flight, necessary for the peculiar habits of the bird, and for obtaining its food; but in the other extreme, in large heavy birds, whose wings are merely required for the purposes of migration or locomotion, flight is obtained with the least possible degree of power, and this condition can only be commanded by a rapid straightforward course through the air.

The sustaining power obtained in flight must depend upon certain laws of action and reaction between relative weights; the weight of a bird, balanced, or finding an abutment, against the fixed inertia of a far greater weight of air, continuously brought into action in a given time. This condition is secured, not by extensive surface, but by great length of wing, which, in forward motion, takes a support upon a wide stratum of air, extending transversely to the line of direction.

The pelican, for example, has wings extending out 10 feet. If the limits of motion imparted to the substratum of air, acted upon by the incline of the wing, be assumed as one foot in thickness, and the velocity of flight as 30 miles per hour, or 2,640 feet per minute, the stratum of air passed over in this time will weigh nearly one ton, or 100 times the weight of the body of the bird, thus giving such an enormous supporting power, that the comparatively small weight of the bird has but little effect in deflecting the heavy length of stratum downwards, and, therefore, the higher the velocity of flight the less the amount of "slip," or power wasted in compensation for descent.

As noticed at the commencement of this paper, large birds may be observed to skim close above smooth water without ruffling the surface; showing that during rapid flight the air does not give way beneath them, but approximates towards a solid support.

In all inclined surfaces, moving rapidly through air, the whole sustaining power approaches toward the front edge; and in order to exemplify the inutility of surface alone, without proportionate length of wing, take a plane, ten feet long by two broad, impelled with the narrow end forward, the first twelve or fifteen inches will be as efficient at a high speed in supporting a weight as the entire following portion of the plane, which may be cut off, thus reducing the effective wing-area of a pelican, arranged in this direction, to the totally inadequate equivalent of two-and-a-half square feet.

One of the most perfect natural examples of easy and long-sustained flight is the wandering albatross. "A bird for endurance of flight probably unrivalled. Found over all parts of the Southern Ocean, it seldom rests on the water. During storms, even the most terrific, it is seen now dashing through the whirling clouds, and now serenely floating, without the least observable motion of its outstretched pinions." The wings of this bird extend fourteen or fifteen feet from end to end, and measure only eight-and-a-half inches across the broadest part. This conformation gives the bird such an extraordinary sustaining power, that it is said to *sleep* on the wing during stormy

weather, when rest on the ocean is impossible. Rising high in the air, it skims slowly down, with absolutely motionless wings, till a near approach to the waves awakens it, when it rises again for another rest.

If the force expended in actually sustaining a long-winged bird upon a wide and unyielding stratum of air, during rapid flight, is but a small fraction of its strength, then nearly the whole is exerted in overcoming direct forward resistance. In the pelican referred to, the area of the body, at its greatest diameter, is about 100 square inches; that of the pinions, eighty. But as the contour of many birds during flight approximates nearly to Newton's solid of least resistance, by reason of this form, acting like the sharp bows of a ship, the opposing force against the wind must be reduced down to one third or fourth part; this gives one-tenth of a horse-power, or about half the strength of a man, expended during a flight of thirty miles per hour. Judging from the action of the living bird when captured, it does not appear to be more powerful than here stated.

The transverse area of a carrier pigeon during flight (including the outstretched wings) a little exceeds the ratio of twelve square inches for each pound, and the wing-surface, or sustaining area, ninety square inches per pound.

Experiments have been made to test the resisting power of conical bodies of various forms, in the following manner: — A thin lath was placed horizontally, so as to move freely on a pivot set midway; at one end of the lath a circular card was attached, at the other end a sliding clip traversed, for holding paper cones, having their bases the exact size of the opposite disc. The instrument acted like a steelyard; and when held against the wind, the paper cones were adjusted at different distances from the centre, according to their forms and angles, in order to balance the resistance of the air against the opposing flat surface. The resistance was found to be diminished nearly in the ratio that the height of the cone exceeded the diameter of base.

It might be expected that the pull of the string of a flying kite

should give some indication of the force of inclined surfaces acting against a current of air; but no correct data can be obtained in this way. The incline of the kite is far greater than ever appears in the case of the advancing wing-surface of a bird. The tail is purposely made to give steadiness by a strong pull backwards from the action of the wind, which also exerts considerable force on the suspended cord, which for more than half its length hangs nearly perpendicularly. But the kite, as a means of obtaining unlimited lifting and tractive power, in certain cases where it might be usefully applied, seems to have been somewhat neglected. For its power of raising weights, the following quotation is taken from Vol. XLI. of the *Transactions of the Society of Arts*, relating to Captain Dansey's mode of communicating with a lee-shore. The kite was made of a sheet of holland exactly nine feet square, extended by two spars placed diagonally, and as stretched spread a surface of fifty-five square feet. "The kite, in a strong breeze, extended 1,100 yards of line five-eighths in circumference, and would have extended more had it been at hand. It also extended 360 yards of line, one and three-quarters of an inch in circumference, weighing sixty pounds. The holland weighed three and a half pounds; the spars, one of which was armed at the head with iron spikes, for the purpose of mooring it, six and three-quarter pounds; and the tail was five times its length, composed of eight pounds of rope and fourteen of elm plank, weighing together twenty-two pounds."

We have here the remarkable fact of ninety-two and a quarter pounds carried by a surface of only fifty-five square feet.

As all such experiments bear a very close relation to the subject of this paper, it may be suggested that a form of kite should be employed for reconnoitring and exploring purposes, in lieu of balloons held by ropes. These would be torn to pieces in the very breeze that would render a kite most serviceable and safe. In the arrangement there should be a smaller and upper kite, capable of sustaining the weight of the apparatus. The lower kite should be as nearly as practicable in the form of a circular flat plane, distended with ribs, with a car

attached beneath like a parachute. Four guy-ropes leading to the car would be required for altering the angle of the plane — vertically with respect to the horizon, and laterally relative to the direction of the wind. By these means the observer could regulate his altitude, so as to command a view of a country, in a radius of at least twenty miles; he could veer to a great extent from side to side, from the wind's course, or lower himself gently, with the choice of a suitable spot for descent. Should the cord break, or the wind fail, the kite would, in either case, act as a parachute, and as such might be purposely detached from the cord, which then being sustained from the upper kite, could be easily recovered. The direction of descent could be commanded by the guy-ropes, these being hauled taut in the required direction for landing.

The author has good reasons for believing that there would be less risk associated with the employment of this apparatus, than the reconnoitring balloons that have now frequently been made use of in warfare.[1]

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[1] The practical application of these suggestions appears to have been anticipated some years previously. In a small work, styled the "History of the Charvolant, or Kite Carriage," published by Longman and Co., appear the following remarks: — "These buoyant sails, possessing immense power, will, as we have before remarked, serve for floating observatories. . . . Elevated in the air, a single sentinel, with a perspective, could watch and report the advance of the most powerful forces, while yet at a great distance. He could mark their line of march, the composition of their force, and their general strength, long before he could be seen by the enemy." Again, at page 53, we have an account of ascents actually made, as follows: — "Nor was less progress made in the experimental department, when large weights were required to be raised or transposed. While on this subject, we must not omit to observe that the first person who soared aloft in the air by this invention was a lady, whose courage would not be denied this test of its strength. An arm-chair was brought on the ground, then lowering the cordage of the kite by slackening the lower brace, the chair was firmly lashed to the mainline, and the lady took her seat. The main-brace being hauled taut, the huge buoyant sail rose aloft with its fair burden, continuing to ascend to the height of 100 yards. On descending, she expressed herself much pleased with the easy motion of the kite, and the delightful prospect she had enjoyed. Soon after this, another experiment of a similar nature took place, when the inventor's son successfully carried out a design not less safe than bold; that of scaling, by this powerful aërial machine, the brow of a cliff 200 feet in perpendicular height. Here, after safely landing, he again took his seat in a chair expressly prepared for the purpose, and, detaching the swivel-line, which kept it at its elevation, glided gently down the cordage to the hand of the director. The buoyant sail employed on this occasion was thirty feet in height, with a proportionate spread of canvas. The rise of the machine was most majestic, and nothing could surpass the steadiness with which it was manœuvred; the certainty with which it answered the action of the braces, and the ease with which its power was lessened or increased. . . . Subsequently to this, an experiment of a very bold and novel character

The wings of all flying creatures, whether of birds, bats, butterflies, or other insects, have this one peculiarity of structure in common. The front, or leading edge, is rendered rigid by bone, cartilage, or a thickening of the membrane; and in most birds of perfect flight, even the individual feathers are formed upon the same condition. In consequence of this, when the wing is waved in air, it gives a persistent force in one direction, caused by the elastic reaction of the following portion of the edge. The fins and tails of fishes act upon the same principle. In the most rapid swimmers these organs are termed "lobated and pointed." The tail extends out very wide transversely to the body, so that a powerful impulse is obtained against a wide stratum of water, on the condition before explained. This action is imitated in Macintosh's screw-propeller, the blade of which is made of thin steel, so as to be elastic. While the vessel is stationary, the blades are in a line with the keel, but during rotation they bend on one side, more or less, according to the speed and degree of propulsion required, and are thus self-compensating; and could practical difficulties be overcome, would prove to be a form of propeller perfect in theory.

In the flying mechanism of beetles there is a difference of arrangement. When the elytra, or wing-cases, are opened, they are checked by a stop, which sets them at a fixed angle. It is probable that these serve as "aeroplanes," for carrying the weight of the insect, while the delicate membrane that folds beneath acts more as a propelling than a supporting organ. A beetle cannot fly with the elytra removed.

The wing of a bird, or bat, is both a supporting and propel-

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was made upon an extensive down, where a wagon with a considerable load was drawn along, whilst this huge machine, at the same time, carried an observer aloft in the air, realising almost the romance of flying."

It may be remarked that the brace-lines here referred to were conveyed down the main-line and managed below; but it is evident that the same lines could be managed with equal facility by the person seated in the car above; and if the main-line were attached to a water-drag instead of a wheeled car, the adventurer could cross rivers, lakes, or bays, with considerable latitude for steering and selecting the point of landing, by hauling on the port or starboard brace-lines as required. And from the uniformity of the resistance offered by the water-drag, this experiment could not be attended with any greater amount of risk than a land flight by the same means.

ling organ, and flight is performed in a rapid course, as follows: — During the down-stroke it can be easily imagined how the bird is sustained; but in the up-stroke, the weight is also equally well supported, for in raising the wing, it is slightly inclined upwards against the rapidly passing air, and as this angle is somewhat in excess of the motion due to the raising of the wing, the bird is sustained as much during the up as the down-stroke — in fact, though the wing may be rising, the bird is still pressing against the air with a force equal to the weight of its body. The faculty of turning up the wing may be easily seen when a large bird alights; for after gliding down its aerial gradient, on its approach to the ground it turns up the plane of its wing against the air; this checks its descent, and it lands gently.

It has before been shown how utterly inadequate the mere perpendicular impulse of a plane is found to be in supporting a weight, when there is no horizontal motion at the time. There is no material weight of air to be acted upon, and it yields to the slightest force, however great the velocity of impulse may be. On the other hand, suppose that a large bird, in full flight, can make forty miles per hour, or 3,520 feet per minute, and performs one stroke per second. Now, during every fractional portion of that stroke, the wing is acting upon and obtaining an impulse from a fresh and undisturbed body of air; and if the vibration of the wing is limited to an arc of two feet, this by no means represents the small force of action that would be obtained when in a stationary position, for the impulse is secured upon a stratum of fifty-eight feet in length of air at each stroke. So that the conditions of weight of air for obtaining support equally well apply to weight of air, and its reaction in producing forward impulse.

So necessary is the acquirement of this horizontal speed, even in commencing flight, that most heavy birds, when possible, rise against the wind, and even run at the top of their speed to make their wings available, as in the example of the eagle, mentioned at the commencement of this paper. It is stated that the Arabs, on horseback, can approach near enough

to spear these birds, when on the plain, before they are able to rise: their habit is to perch on an eminence, where possible.

The tail of a bird is not necessary for flight. A pigeon can fly perfectly with this appendage cut short off: it probably performs an important function in steering, for it is to be remarked, that most birds that have either to pursue or evade pursuit are amply provided with this organ.

The foregoing reasoning is based upon facts, which tend to show that the flight of the largest and heaviest of all birds is really performed with but a small amount of force, and that man is endowed with sufficient muscular power to enable him also to take individual and extended flights, and that success is probably only involved in a question of suitable mechanical adaptations. But if the wings are to be modelled in imitation of natural examples, but very little consideration will serve to demonstrate its utter impracticability when applied in these forms. The annexed diagram, Fig. 1, would be about the proportions needed for a man of medium weight. The wings, *a a*, must extend out sixty feet from end to end, and measure four feet across the broadest part. The man, *b*, should be in a horizontal position, encased in a strong framework, to which the wings are hinged at *c c*. The wings must be stiffened by elastic ribs, extending back from the pinions. These must be trussed by a thin band of steel, *e e*, Fig. 2, for the purpose of diminishing the weight and thickness of the spar. At the front, where the pinions are hinged, there are two levers attached, and drawn together by a spiral spring, *d*, Fig. 2, the tension of which is sufficient to balance the weight of the body and machine, and cause the wings to be easily vibrated by the movement of the feet acting on treadles. This spring serves the purpose of the pectoral muscles in birds. But with all such arrangements the apparatus must fail — *length of wing is indispensable!* and a spar thirty feet long must be strong, heavy, and cumbrous; to propel this alone through the air, at a high speed, would require more power than any man could command.

In repudiating all imitations of natural wings, it does not follow that the only channel is closed in which flying mechanism

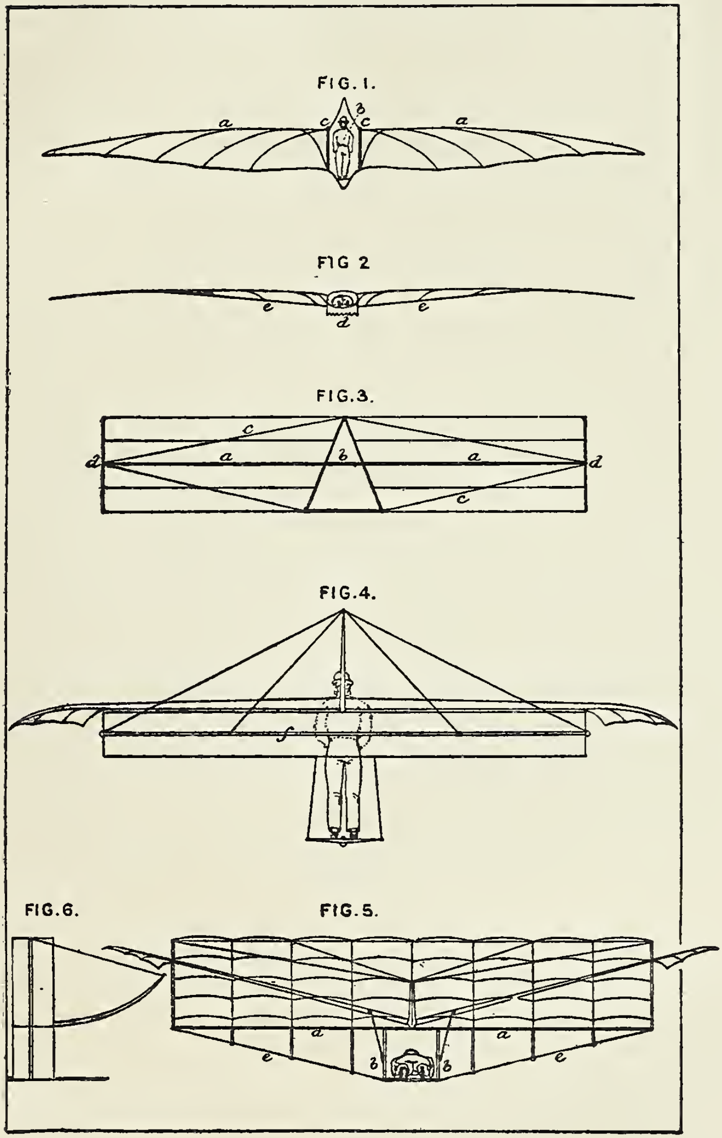
FIG. 1.
FIG 2
FIG. 3.
FIG. 4.
FIG. 6.
FIG. 5.

may prove successful. Though birds do fly upon definite mechanical principles, and with a moderate exertion of force, yet the wing must necessarily be a vital organ and member of the living body. It must have a marvellous self-acting principle of repair, in case the feathers are broken or torn; it must also fold up in a small compass, and form a covering for the body.

These considerations bear no relation to artificial wings; so in designing a flying-machine, any deviations are admissible, provided the theoretical conditions involved in flight are borne in mind.

Having remarked how thin a stratum of air is displaced beneath the wings of a bird in rapid flight, it follows that in order to obtain the necessary *length* of plane of supporting heavy weights, the surfaces may be superposed, or placed in parallel rows, with an interval between them. A dozen pelicans may fly one above the other without mutual impediment, as if framed together; and it is thus shown how two hundred weight may be supported in a transverse distance of only ten feet.

In order to test this idea, six bands of stiff paper, three feet long and three inches wide, were stretched at a slight upward angle, in a light rectangular frame, with an interval of three inches between them, the arrangement resembling an open Venetian blind. When this was held against a breeze, the lifting power was very great, and even by running with it in a calm it required much force to keep it down. The success of this model led to the construction of one of a sufficient size to carry the weight of a man. Fig. 3 represents the arrangement. *a a* is a thin plank, tapered at the outer ends, and attached at the base to a triangle, *b*, made of similar plank, for the insertion of the body. The boards, *a a*, were trussed with thin bands of iron, *c c*, and at the ends were vertical rods, *d d*. Between these were stretched five bands of holland, fifteen inches broad and sixteen feet long, the total length of the web being eighty feet. This was taken out after dark into a wet piece of meadow land, one November evening, during a strong breeze, wherein it became quite unmanageable. The wind acting upon the already tightly-stretched webs, their united pull caused the central boards to

bend considerably, with a twisting, vibratory motion. During a lull, the head and shoulders were inserted in the triangle, with the chest resting on the base board. A sudden gust caught up the experimenter, who was carried some distance from the ground, and the affair falling over sideways, broke up the right-hand set of webs.

In all new machines we gain experience by repeated failures, which frequently form the stepping-stones to ultimate success. The rude contrivance just described (which was but the work of a few hours) had taught, first, that the webs, or aeroplanes, must not be distended in a frame, as this must of necessity be strong and heavy, to withstand their combined tension; second, that the planes must be made so as either to furl or fold up, for the sake of portability.

In order to meet these conditions, the following arrangement was afterwards tried: — *a a*, Figs. 4 and 5, is the main spar, sixteen feet long, half an inch thick at the base, and tapered, both in breadth and thickness, to the end; to this spar was fastened the panels *b b*, having a base-board for the support of the body. Under this, and fastened to the end of the main spar, is a thin steel tie-band, *e e*, with struts starting from the spar. This served as the foundation of the superposed aeroplanes, and, though very light, was found to be exceedingly strong; for when the ends of the spar were placed upon supports, the middle bore the weight of the body without any strain or deflection; and further, by a separation at the base-board, the spars could be folded back, with a hinge, to half their length. Above this were arranged the aeroplanes, consisting of six webs of thin holland, fifteen inches broad; these were kept in parallel planes, by vertical divisions, two feet wide, of the same fabric, so that when distended by a current of air, each two feet of web pulled in opposition to its neighbour; and finally, at the ends (which were each sewn over laths), a pull due to only two feet had to be counteracted, instead of the strain arising from the entire length, as in the former experiment. The end-pull was sustained by vertical rods, sliding through loops on the transverse ones at the ends of the webs, the whole of which could fall flat on the

spar, till raised and distended by a breeze. The top was stretched by a lath, *f*, and the system kept vertical by staycords, taken from a bowsprit carried out in front, shown in Fig. 6. All the front edges of the aeroplanes were stiffened by bands of crinoline steel. This series was for the supporting arrangement, being equivalent to a length of wing of ninety-six feet. Exterior to this, two propellers were to be attached, turning on spindles just above the back. They are kept drawn up by a light spring, and pulled down by cords or chains, running over pulleys in the panels *b b*, and fastened to the end of a swivelling cross-yoke, sliding on the base-board. By working this cross-piece with the feet, motion will be communicated to the propellers, and by giving a longer stroke with one foot than the other, a greater extent of motion will be given to the corresponding propeller, thus enabling the machine to turn, just as oars are worked in a rowing boat. The propellers act on the same principle as the wing of a bird or bat: their ends being made of fabric, stretched by elastic ribs, a simple waving motion up and down will give a strong forward impulse. In order to start, the legs are lowered beneath the base-board, and the experimenter must run against the wind.

An experiment recently made with this apparatus developed a cause of failure. The angle required for producing the requisite supporting power was found to be so small, that the crinoline steel would not keep the front edges in tension. Some of them were borne downwards and more on one side than the other, by the operation of the wind, and this also produced a strong fluttering motion in the webs, destroying the integrity of their plane surfaces, and fatal to their proper action.

Another arrangement has since been constructed, having laths sewn in both edges of the webs, which are kept permanently distended by cross-stretchers. All these planes are hinged to a vertical central board, so as to fold back when the bottom ties are released, but the system is much heavier than the former one, and no experiments of any consequence have as yet been tried with it.

It may be remarked that although a principle is here defined,

yet considerable difficulty is experienced in carrying the theory into practice. When the wind approaches to fifteen or twenty miles per hour, the lifting power of these arrangements is all that is requisite, and, by additional planes, can be increased to any extent; but the capricious nature of the ground-currents is a perpetual source of trouble.

Great weight does not appear to be of much consequence, *if carried in the body;* but the aeroplanes and their attachments seem as if they were required to be very light, otherwise, they are awkward to carry, and impede the movements in running and making a start. In a dead calm, it is almost impracticable to get sufficient horizontal speed, by *mere running* alone, to raise the weight of the body. Once off the ground, the speed must be an increasing one, if continued by suitable propellers. The small amount of experience as yet gained, appears to indicate that if the aeroplanes could be raised in detail, like a superposed series of kites, they would first carry the weight of the machine itself, and next relieve that of the body.

Until the last few months no substantial attempt has been made to construct a flying-machine, in accordance with the principle involved in this paper, which was written seven years ago. The author trusts that he has contributed something towards the elucidation of a new theory, and shown that the flight of a bird in its performance does not require that enormous amount of force usually supposed, and that in fact birds do not exert more power in flying than quadrupeds in running, but considerably less; for the wing movements of a large bird, travelling at a far higher speed in air, are very much slower; and, where weight is concerned, great velocity of action in the locomotive organs is associated with great force.

It is to be hoped that further experiments will confirm the correctness of these observations, and with a sound working theory upon which to base his operations, man may yet command the air with the same facility that birds now do.

The CHAIRMAN: "I think the paper just read is one of great interest and importance, especially as it points out the true mechanical explanation of the curious problem, as to how and

why it is that birds of the most powerful flight always have the longest and narrowest wings. I think it quite certain, that if the air is ever to be navigated, it will not be by individual men flying by means of machinery; but that it is quite possible vessels may be invented, which will carry a number of men, and the motive force of which will not be muscular action. We must first ascertain clearly the mechanical principles upon which flight is achieved; and this is a subject which has scarcely ever been investigated in a scientific spirit. In fact, you will see in our best works of science, by the most distinguished men, the account given of the anatomy of birds is, that a bird flies by inflating itself with warm air, by which it becomes buoyant, like a balloon. The fact is, however, that a bird is never buoyant. A bird is immensely heavier than the air. We all know that the moment a bird is shot it falls to the earth; and it must necessarily do so, because one of the essential mechanical principles of flight is weight, without it there can be no momentum, and no motive force capable of moving through atmospheric currents.

"Until I read Mr. Wenham's paper, a few weeks since, I was puzzled by the fact, that birds with long and very narrow wings seem to be not only as efficient fliers, but much more efficient fliers than birds with very large, broad wings. If you observe the flight of the common heron — which is a bird with a very large wing, disposed rather in breadth than in length — you will notice that it is exceedingly slow, and that it has a very heavy, flapping motion. The common swallow, on the other hand, is provided with a long and narrow wing, and I never understood how it was that long-winged birds, such as these, achieved so rapid a flight, until I read Mr. Wenham's paper. Although I do not profess to be able to follow the elaborate calculations which he has laid before us, I think I now understand the explanation he has given. His explanation of the action of narrow wings upon the air is, that it is precisely like the action of the narrow vanes of the ship's screw in water, and that the resisting power of the screw is the same, or nearly the same,

whether you have the total area of revolution covered by solid surface, or traversed by long and narrow vanes in rotation.

"If Mr. Wenham's explanation be nearly correct, that supposing this implement (referring to a model) to be carried forward by some propelling power, the sustaining force of the whole area is simply the sustaining force of the narrow band in front. This, however, is a matter which will have to be decided by experiment. It certainly appears to explain the phenomena of the flight of birds. There are one or two observations in the paper I do not quite agree with. Although I have studied the subject for many years, I have not arrived at Mr. Wenham's conclusion that the upward stroke of a bird's wing has precisely the same effect as a downward stroke in sustaining. An upward stroke has a contrary effect to the downward stroke; it has a propelling power certainly, but I believe that the sustaining power of a bird's flight is due entirely to the downward stroke. I should be glad to hear what Mr. Wenham may have to say upon this. My belief is, that an upward stroke must have, so far as sustaining is concerned, a reverse action to the downward stroke.

"Then with regard to another observation of Mr. Wenham's, that the tails of birds are used as rudders. I believe this to be an entire mistake; for if the tail of a bird could have the slightest effect in guiding, the vane of it must be disposed perpendicularly, and not horizontally, or nearly so, as at present.

"If you cut off the tail of a pigeon, you will find that he can fly and turn perfectly well without it. He may be a little awkward about it at first, but that is because he has lost his balancing power. We all know that it is a common thing to see a sparrow without his tail, therefore, I do not in the least believe that tails have any effect in guiding. They have an important effect in stopping progress, and, undoubtedly, that is one of the necessary elements of turning. If a bird comes close over your head, and is frightened, you will find his claws distended and his tail spread out as a fan, to stop the momentum of his flight. These are the two only observations with which I cannot agree; but as regards the explanation he has given as to the resistance

offered by long and narrow wings, he has made an important discovery."

Mr. Wenham: "With regard to the wing not affording support to the bird during the upward stroke, some of the largest birds move their wings slowly, that is, with a less number than sixty strokes per minute. Now, as a body free to fall must descend fifteen feet in one second, whether in horizontal motion or not, it appears clear to me that there must be some counteracting effect to prevent this fall. When the wing has reached the limit of the down-stroke, it is inclined upwards in the direction of motion, consequently the rush of air caused by the forward speed, weight, and momentum of the bird against the under surface of the wing, supports the weight, even though the wing is rising in the up-stroke at the time. In corroboration of my theory, I will read an extract from Sir George Cayley, who made a large number of experiments. He says, in page 83, of Vol. xxv., 'Nicholson's Journal': —'The stability in this position, arising from the centre of gravity, being below the point of suspension, is aided by a remarkable circumstance that experiment alone could point out. In very acute angles with the current, it appears that the centre of resistance in the sail does not coincide with the centre of its surface, but is considerably in front of it. As the obliquity of the current decreases, these centres approach and coincide when the current becomes perpendicular to the plane, hence any heel of the machine backwards or forwards removes the centre of support behind or before the point of suspension.'

"From this discovery, it seems remarkable that Sir George Cayley, finding that at high speeds with very oblique incidences the supporting effect became transferred to the front edge, the idea should not have occurred to him that a narrow plane, with its long edge in the direction of motion, would have been equally effective. I may give another illustration. We all know, from our schoolboy experience, that ice which would not be safe to stand upon, is found to be quite strong enough to bear heavy bodies passing over it, so long as rapid motion is kept up, and then it will not even crack. We know, also, that in driving

through a marshy part of road, in which you expect the wheels to sink in up to the axles, you may pass over much more easily by increasing the speed. In both these examples there is a greater weight passed over in a given time, and consequently a better support obtained. The ice will not become deflected; neither has the mud time to give way. At a slow speed the same effect may be obtained by extending the breadth of the wheel. Thus, suppose an ordinary wheel to sink ten inches, if you double this width it will sink only five inches; and so on, until by extending the wheel into a long roller you may pass over a quicksand with perfect safety. Now, Nature has carried out this principle in the long wings of birds, and in the albatross it is seen in perfection."

(*Extracts from the "Technology Review," April, 1910.*)

THE BLUE HILL METEOROLOGICAL OBSERVATORY.

1885–1910.

When a private scientific establishment has completed an existence of a quarter of a century, it may be considered as a permanent institution and as such worthy of public notice.

The Blue Hill Meteorological Observatory was founded in 1885 by A. Lawrence Rotch.[1]

The earliest measurements in America of the height and velocity of clouds, by trigonometrical and other methods, were made at Blue Hill in 1890–91, and were repeated in 1896–97 as part of an international system. These researches and the first applications of kites in 1894, at the suggestion of Mr. W. A. Eddy, to obtain meteorological observations in the upper air by means of instruments, recording graphically and continuously, made the Observatory widely known. The use of cellular kites flown with steel wire and controlled by a power windlass originated at Blue Hill, and was subsequently adopted by the United States Weather Bureau and many stations abroad.

In 1899 kites were used to elevate the terminal wires in experiments in wireless telegraphy between Blue Hill and Cambridge. In 1901 Professor Rotch and Mr. Sweetland made a transatlantic voyage to demonstrate that kites might be flown at sea in calm weather by utilizing the motion of the vessel to create an artificial wind. A more complete exploration of the air over the ocean by this method was made by Mr. Clayton in a voyage to Gibraltar in 1905, after which, on a steam yacht sent to the equatorial Atlantic through the coöperation with Mr. Rotch of a French colleague, M. Teisserenc de Bort, both kites and pilot-balloons were used to investigate the trade-winds. The unprecedented height of three miles was reached by kites at Blue Hill in 1900, and kite flights are still made there once a month.

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[1] See page 149.

To obtain temperatures at much greater heights, free balloons carrying self-recording instruments were employed for the first time in this country by Professor Rotch during the St. Louis Exposition. In this and the following four years, of the seventy-six balloons sent up from St. Louis, seventy-two were recovered. The heights occasionally exceeded ten miles, and a temperature of 111° F. below zero was registered, which is one of the lowest natural temperatures ever observed. Such sounding balloons sent up by Professor Rotch from Pittsfield, Mass., are not so often recovered, but pilot-balloons, followed by theodolites from Blue Hill, permit the direction and speed of the upper currents to be determined up to great heights in this region.

Aerological observations, as those in the free air are called, are now conducted at many stations throughout the world, and it is obvious that such observations, while undertaken in the interest of pure science, have a prospective value for aerial navigation, and it is probable that a station like Blue Hill, which already has counterparts, both government and private, will be necessary in each region to ascertain the conditions which may be expected to be encountered at different heights in the atmosphere by aerial craft.

Professor Rotch has been ably assisted in his work. Mr. S. P. Fergusson joined the Observatory staff in 1887 and is still a member. Mr. H. Helm Clayton was a member for a period of twenty-three years, with some interruptions. His investigations have brought distinction to himself and the Observatory. Mr. A. E. Sweetland, who died after eight years' service, was succeeded in 1903 by Mr. L. A. Wells, and he, together with Mr. Fergusson and Mr. L. H. Palmer, are at present the assistants of Professor Rotch, who assumes the direction of the work and the burden of the expense.

The purpose of the Observatory continues to be mainly research, free from prescribed duties and independent of outside control. It is, however, attached to Harvard University, and publication is made in the *Annals of the Astronomical Observatory of Harvard College*. The building, on the summit

of Great Blue Hill,[1] in the Metropolitan Park Reservation, has been three times enlarged, and the annual expense has been increased to $5,000 a year. Perhaps the most valuable part of the equipment is a library of about ten thousand books and pamphlets. To avoid interference with the work, the Observatory is closed to the public.

The value of a meteorological record increases with each year of observation, and, while twenty-five years homogeneous observations of all the meteorological elements constitute a unique series in America, it is still too short a period to determine secular changes of climate. Therefore it is to be hoped that the Observatory may have its existence prolonged, with unchanged environment and methods of observation, to the close of the century; but, since this transcends the life of an individual, the duty must devolve on the University to which it is allied.

[From Aero. Ann., 1897.]

MISCELLANY.

THE ALBATROSS.

The contour of the albatross, shown in Plate XVII., is taken from Alfred Newton's "Dictionary of Birds," and the following quotation comes from the same source: "In process of time the name has become definitely limited to the larger species of *Diomedeidæ*, a family of the group *Tubinares*, and especially to the largest species of the genus *Diomedea exulans*, the 'Man-of-war bird' or wandering albatross of many authors. Of this, though it has been so long the observed of all observers among voyagers to the Southern Ocean, no one seems to have given, from the life, its finished portrait on the wing, and hardly such a description as would enable those who have not seen it to form an idea of its look.

"The diagrammatic sketch by Captain (now Professor) Hutton, here introduced, is probably a more correct representation of it than can be found in the conventional figures which abound in books. The ease with which this bird maintains itself in the air, 'sailing' for a long while without any perceptible motion of its wings, whether gliding over the billows, or boldly shooting aloft, again to descend and possibly alight on the surface, has been

[1] The summit is 10.4 miles S.S.W. from the Massachusetts State House in Boston. Travellers from New York to Boston, via Providence, may see the Observatory on the right, about fifteen minutes before reaching Boston. See Illustration, Plate XIV.

dwelt upon often enough, as has its capacity to perform these feats equally in a seeming calm or in the face of a gale; but more than this is wanted, and one must hope that a series of instantaneous photographs may soon be obtained which will show the feathered aeronaut with becoming dignity.

"The most vivid description is perhaps that given by Mr. Froude in his 'Oceana,' of which a part may here be quoted. 'The albatross wheels in circles round and round, and forever round the ship, now far behind, now sweeping past in a long rapid curve, like a perfect skater on an untouched field of ice. There is no effort; watch as closely as you will, you rarely or never see a stroke of the mighty pinion. The flight is generally near the water, often close to it. You lose sight of the bird as he disappears in the hollow between the waves, and catch him again as he rises over the crest; but how he rises and whence comes the propelling force is to the eye inexplicable; he alters merely the angle at which the wings are inclined; usually they are parallel to the water and horizontal, but when he turns to ascend, or makes a change in his direction, the wings then point at an angle, one to the sky, the other to the water.'

"The mode in which the 'sailing' of the albatross is effected has been much discussed, but there can be little doubt that Professor Hutton is right in declaring ("Ibis," 1865, p. 296) that it is only 'by combining, according to the laws of mechanics, this pressure of the air against his wings with the force of gravity, and by using his head and tail as bow and stern rudders, that the albatross is enabled to sail in any direction he pleases, so long as his momentum lasts.'

"Much discrepancy, at present inexplicable, exists in the accounts given by various writers of the expanse of wing in this species. We may set aside as a gross exaggeration the assertion that examples have been obtained measuring 20 feet, but Dr. George Bennett, of Sydney, states that he has 'never seen the spread of the wings greater than 14 feet.' Recently Mr. J. F. Green says that, out of more than one hundred which he had caught and measured, the largest was 11 feet 4 inches from tip to tip, a statement exactly confirmed, he adds, by the forty years' experience of a ship-captain who had always made a point of measuring these birds, and had never found one over that length.

"In the adult bird the plumage of the body is white, more or less mottled above by fine wavy bars, and the quill feathers of the wings are brownish-black. The young are suffused with slaty brown, the tint becoming lighter as the bird grows older. It is found throughout the Southern Ocean, seldom occurring northward of latitude 30° S., and is invariably met with by ships that round the Cape of Good Hope or pass the Strait of Magellan."

From "L'Empire de l'Air," by Mouillard, 1881 (see Smithsonian Report, 1892):

"The most stirring, exciting sight (the word is not too strong) is to stand in the vulture roost on the Mokatan ridge, near Cairo, and to look upon the *Gyps fulvus* (tawny vulture) passing within five yards in full flight. . . . All my life I shall remember the first flight of these birds which I saw, the great tawny vultures of Africa. I was so impressed that all day long I could think of nothing else; and indeed there was good cause, for it was a practical perfect demonstration of all my preconceived theories concerning the possibilities of artificial flight in a wind. Since then I have observed thousands of vultures. I have disturbed many of the vast flocks of these birds, and yet, even now, I cannot see one individual passing through the air without following him with my eyes until he disappears in the distant horizon. . . .

"The vulture's needs are few, and his strength is moderate. To earn his living he but needs to sight the dead animal from afar. And so, what does he know? He knows how to rise, how to float aloft, to sweep the field with keen vision, to sail upon the wind without effort, till the carcass is seen, and then to descend slowly after careful reconnaissance and assurance that he may

alight without danger, that he will not be surprised and compelled to precipitous and painful departure. And so he has evolved a peculiar mode of flight; he sails and spends no force, he never hurries, he uses the wind instead of his muscles, and the wing-flap occasionally seen is meant to limber up rather than to hasten through the air. And so the true model to study is the vulture — the great vulture. Beside him the stork is as a wren, the kite a mere butterfly, the falcon a pin-feather. Whoso has for five minutes had the fortune to see the Nubian vulture in full sail through the air, and has not perceived the possibility of his imitation by man, is — I will not say of dull understanding, but certainly inapt to analyze and to appreciate."[1]

As to sailing flight, none of the old-time falconers doubted in the least its existence. They observed it every day, and they knew that the wind was a necessary condition. Nobody troubled himself about an explanation in those days; but later on, when physicists attempted to explain the mechanics of flight and succeeded in conceiving the action of the wing stroke and the effects of air resistances, sailing flight appeared to them as a physical impossibility. They said that it was impossible to admit that a bird, suspended at a fixed point in the sky, should find in the action of the wind sufficient power to advance against that wind. As well, said they, might we throw an inert mass into a flowing river, and expect the current to cause the body to advance up-stream. And yet, modern observers have contested this verdict. M. d'Esterno and M. Mouillard demonstrated that, unless we absolutely disbelieve ocular evidence, we must accept the actual fact that sailing flight is possible, even if we have to admit that our present mechanical knowledge is insufficient to explain it. — *Marey. Inst. of France.*

LILIENTHAL wrote as follows under date of April 17, 1896: "I am now engaged in constructing an apparatus in which the position of the wings can be changed during flight in such a way that the balancing is not effected by changing the position of the centre of gravity of the body. In my opinion this means considerable progress, as it will increase the safety. This will probably cause me to give up again the double sailing surfaces as it will do away with the necessity which led me to adopt them."

FLAPPING wings may be imitated, but only with small models; the increased strength and weight of material necessary for larger apparatus, and the great motive power required for alternative action, have proved to be obstacles not yet overcome. — *Mouillard, 1894.*

WE must not allow ourselves to be deceived as to the form of the bird's wing. It is always more curved when not spread than when the bird is resting its weight upon it in the air. Besides which, the curve, which in the beginning appears to be considerably stronger towards the front edge, becomes somewhat more uniform as soon as the quills are bent straighter at their roots by the pressure of the air from beneath. — *Lilienthal, March, 1895.*

MY investigations concerning the effects of curved wings had one result which was quite unexpected, namely, that the air resistance is not perpendic-

[1] Mouillard in his tables gives the following figures concerning the Nubian vulture: Weight of bird, 8152 grams; surface within contour, 1.11295 sq. meters; spread of wings, 2.66 meters; mean width of wing, .46 meters. One square meter sustains 7323 grams. Relative surface required to sustain 80 kilos., or 176.4 lbs. avoirdupois, 10.88 sq. meters, or 117 sq. feet, 16 sq. inches.

ular to the chord of the profile curve, but that in certain impact angles of the air its direction inclines forward, with a perceptible drawing component.[1] —*Lilienthal, March, 1895.*

Lilienthal wrote, May 28, 1896: "I would finally remark that bodily strength and dexterity are of less consequence than the general intelligence and the gift of perception in technical matters when selecting the men [for gliding experiments]."

MISCELLANY.

1910.

THE METHOD WHICH BROUGHT SUCCESS.

In September, 1901, Mr. Wilbur Wright in addressing the Western Society of Engineers said: "If I take this piece of paper, and after placing it parallel with the ground, quickly let it fall, it will not settle steadily down as a staid, sensible piece of paper ought to do, but it insists upon contravening every recognized rule of decorum, turning over and darting hither and thither in the most erratic manner, much after the style of an untrained horse. Yet this is the style of steed that men must learn to manage before flying can become an every day sport. The bird has learned this art of equilibrium, and learned it so thoroughly that its skill is not apparent to our sight. We only learn to appreciate it when we try to imitate it. Now, there are two ways of learning how to ride a fractious horse; one is to get on him and learn by actual practice how each motion and trick may best be met; the other is to sit on a fence and watch the beast a while, and then retire to the house and at leisure figure out the best way of overcoming his jumps and kicks. The latter system is the safest, but the former, on the whole, turns out the larger proportion of good riders. It is much the same in learning to ride a flying-machine; if you are

[1] *Mit nicht unerheblich ziehender Componente.*

For Lilienthal's mathematical treatment of this subject see "Zeitschrift für Luftschiffahrt," February and March, 1895, and also the very interesting manual entitled "Taschenbuch für Flugtechniker und Luftschiffer," by Captain H. W. L. Moedebeck, published by W. H. Kühl, Berlin, 1895.

looking for perfect safety, you will do well to sit on a fence and watch the birds, but if you really wish to learn, you must mount a machine and become acquainted with its tricks by actual trial." (Smithsonian Report, 1902, p. 134.)

MOTORLESS FLIGHT.

EXPERIMENTERS WHO INTEND to devote themselves exclusively to the development of the motorless flying-machine will be interested in reading the following authors:

A. M. WELLINGTON. "The Mechanics of Flight," *Engineering News*, New York, Oct. 12, 1893.

WILBUR WRIGHT. Report of the Smithsonian Institution for the year ending June 30, 1902, page 147.

WILBUR WRIGHT. "Flying as a Sport," *Scientific American*, New York, Feb. 29, 1908.

L. P. MOUILLARD. *The Aeronautical Annual*, No. 3, 1897, pages 158 and 159.

OCTAVE CHANUTE. *The Aeronautical Annual*, No. 2, 1896, pages 60–76. The Same, No. 3, 1897, pages 98–127.

As stated on other pages, the Smithsonian Reports may be found in the principal public libraries of the United States, and the three issues of "The Aeronautical Annual," 1895, 1896, and 1897, may be found in the public libraries of every city in the United States having a population of 100,000 or more. The editor is uncertain whether the "Engineering News" for 1893 will be found in many public libraries. Mr. Wellington's paper was also printed in the "Proceedings of the International Conference on Aerial Navigation held in Chicago in 1893;" published in 1894 by "The American Engineer and Railroad Journal," New York. This book contains over four hundred pages of valuable matter. It is rare.

It is very unfortunate that so much of the literature which would be valuable to the students of aviation is out of print. Original editions were usually small, but they were larger than was necessary to meet the demand at the time of publication.

TWO HUNDRED PAGES OF READING MATTER VALUABLE TO THE STUDENTS OF AVIATION.

See the Annual Reports of the Smithsonian Institution for the years given below. These may be found in the principal public libraries of the United States and in many European libraries.

Since 1897 the Reports have borne two dates upon the back of binding. The lower date is that of publication. The upper date is the one here given.

1892. The Empire of the Air.
By L. P. Mouillard, pp. 397–463.

1897. On Soaring Flight.
By E. C. Huffaker, pp. 183–206.

1900. Lord Rayleigh on Flight, p. 195.

1900. The Langley Aerodrome, pp. 197–216.

1901. The Greatest Flying Creature.
By Langley and Lucas, pp. 649–659.

1902. Some Aeronautical Experiments.
By Wilbur Wright, pp. 133–148.

1903. Aerial Navigation.
By Octave Chanute, pp. 173–181.

1904. Experiments with the Langley Aerodrome.
By S. P. Langley, pp. 113–125.

1908. The Present Status of Military Aeronautics.
By Major George O. Squier, U.S.A., pp. 117–144.

1908. Aviation in France in 1908.
By Pierre-Roger Jourdain, pp. 145–159.

MEMORABLE EVENTS.

FLIGHTS WITH MOTOR AEROPLANES.

Dec. 17, 1903.

WILBUR WRIGHT in North Carolina flew 852 feet. *This was the first successful flight in history.*

Nov. 9, 1904.

WILBUR WRIGHT near Dayton, Ohio, flew 3 miles.

Oct. 5, 1905.

WILBUR WRIGHT near Dayton, Ohio, flew 24 miles.

Sept. 9, 1908.

ORVILLE WRIGHT at Fort Myer, Va., broke three world's records. In the morning he flew 57 minutes, 31 seconds, breaking the record for duration of flight. In the afternoon he made a flight of 62 minutes, 15 seconds, thus breaking his own record. A third flight was made with Lieutenant Lahm as passenger. Time 6 minutes, 10 seconds. This surpassed the world's record for doubles.

Sept. 21, 1908.

WILBUR WRIGHT at Auvours made a record-breaking flight of 1 hour, 31 minutes, 20 seconds.

Dec. 31, 1908.

WILBUR WRIGHT at Auvours won Michelin prize by a flight of 2 hours, 20 minutes, 23 seconds.

July 25, 1909.

LOUIS BLÉRIOT made the first flight across the English Channel.

July 30, 1909.

ORVILLE WRIGHT made cross-country flight of 10 miles. Fort Myer, Va., to Alexandria and return; over very difficult country.

Aug. 27, 1909.

HENRI FARMAN at Reims flew 112 miles in 3 hours, 4 minutes, 57 seconds, winning first prize for distance. Hubert Latham at Reims won first prize for altitude, 508 feet.

Aug. 28, 1909.

GLENN H. CURTISS at Reims flew 20 kilometers in 15 minutes, 50⅗ seconds, winning the Gordon-Bennett International Cup.

Sept. 8, 1909.

S. F. CODY in England made cross-country flight of 40 miles.

Sept. 18, 1909.

ORVILLE WRIGHT at Berlin, with Captain Englehardt as passenger, made flight of 1 hour, 35 minutes, 47 seconds.

Oct. 4, 1909.

WILBUR and ORVILLE WRIGHT. The former at New York made flight above Hudson River to Grant's tomb and return, 21 miles. The latter in Berlin reached altitude of 1600 feet.

Oct. 18, 1909.

COUNT DE LAMBERT made flight from Juvisy to Eiffel Tower and return, 31 miles.

Nov. 3, 1909.

HENRI FARMAN at Mourmelon flew 4 hours, 17 minutes, 53 seconds, breaking world's records for duration and distance.

Dec. 1, 1909.

HUBERT LATHAM at Mourmelon rose 1500 feet.

Jan. 12, 1910.

LOUIS PAULHAN at Los Angeles reached altitude of 4165 feet, surpassing world's record.

April 23, 1910.

CLAUDE GRAHAME-WHITE flew from London to a point near Lichfield, 113 miles. Left Wormwood Scrubs at 5.15 A.M., Arr. Clifton, near Rugby, 7.20 A.M.; Left Clifton, 8.25 A.M., Arr. Hademore Crossing, 9.20 A.M.

April 27 and 28, 1910.

LOUIS PAULHAN flew from London to Manchester, 186 miles, winning Daily Mail Prize of $50,000.

Left London, 5.20 P.M., Arr. Lichfield, 8.10 P.M., April 27; Left Lichfield, 4.09 A.M., Arr. Manchester, 5.30 A.M., April 28. Total time of flight, 4 hours, 11 minutes.

EDITORIAL.

1910.

THE FUTURE OF AVIATION.

IN comparing the Stockton and Darlington railway and its equipment with the transcontinental roads and trains of to-day, or in comparing Fulton's "Clermont" with the "Mauretania," we see what may be evolved from crude prototypes.

If, in the early years of the last century, there were men who predicted the developments in transit which were destined to come, they were undoubtedly deemed visionary. As a matter of fact, they were so, but their dreams have come true.

It is probable that the forecasts of those sanguine ones were lightly regarded and perhaps they were told, "You cannot see the limitations of these locomotives and steamboats; you do not in the least know whether the obstacles which will be met in trying to adapt them to the larger uses of mankind will be surmountable or not." That would have been just criticism and it may illustrate the position in which men stand to-day in relation to the problems of aerial travel.

Aviation as a sport is here and it is here to stay. Military experts seem to be agreed that in the unfortunate event of war the dynamic flying-machine in its present state of development will be of great importance for scouting purposes. These experts are far from being in agreement concerning the utility of the flying-machine for offensive purposes in warfare.

Leaving aside the adaptability of the flying-machine to military and sporting purposes and considering its strictly utilitarian value in time of peace, it may be said that those who have given the most study to the subject of aviation seem to

agree in thinking that at no distant day a useful machine will be developed. As to the possible *extent* of the useful service which it may render in the future, we are in a state of ignorance. There are conservatives and there are visionaries. Looking backward a few centuries to the time when man began to conquer distance and looking at his present powers, we see that the visionaries have come out ahead.

The great utilitarian task which is now before us is to navigate the air through darkness, fog, and storm. Can the obstacles be overcome?

Looking down a few hundred feet from the summit of a low mountain opposite the entrance to one of the very long Alpine tunnels, the sinuous, glittering line of rails may be seen; it vanishes in a black pin-hole at the steep base of a mountain of rock thousands of feet high. In the earlier time what a dead wall was that! How would it have appeared to George Stephenson?

Now a train comes along, it disappears, it will emerge miles away.

However it may be with individuals, mankind itself is undaunted in the face of obstacles.

FROM THE INTRODUCTION TO
THE AERONAUTICAL ANNUAL, NO. 1, 1895.

IF this compilation should happily bring any new workers into the field of aeronautical experiment, the hopes of the editor will be amply fulfilled.

EXTRACT FROM A LETTER TO THE EDITOR
DATED DAYTON, OHIO, JANY. 15TH, 1908.

The old Annuals were largely responsible for the active interest which led us to begin experiment in aeronautics.

Very truly yours,

Wright Bros.